Handbook of Research on

Climate Change Impact on Health and Environmental Sustainability

Soumyananda Dinda

Handbook of Research on Climate Change Impact on Health and Environmental Sustainability

Soumyananda Dinda
Sidho-Kanho-Birsha University, India

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While climate change is expected to exacerbate human health risks, it also provides an excellent opportunity for defining and implementing preventive actions. Developing nations like India, with low infrastructure facilities, limited resources, varied development priorities and, often with large population, are particularly vulnerable to health impacts - more so under the climate change regime. The greatest challenge facing the current Indian health service provisioning system is that it has to cater to the health service needs of its large population within a short time and with sustainable impact. Limited health 'cure infrastructure' (low per capita availability of doctor, hospital beds, etc.), lack of qualified health practitioners, absence of a strong monitoring system in disease surveillance and rising cost of 'cure infrastructure' are some of the major drawbacks of the existing system in India. There is therefore, a need for mainstreaming more preventive measures which will enhance human health resilience and make the population less exposed and more resilient to the predicted impacts of climate change. To provide preventive care to the Indian population, a paradigm shift in strategy is required. The new regime needs to emphasize on an integration of 'traditional preventive health care systems' with modern cure targeted pharmaceuticals and non-health sector interventions. Such a system is expected to reduce the long term demand for cure infrastructure and will provide a more holistic inclusive solution to the Indian problems.

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Tonmoy Chatterjee, Ananda Chandra College, India
Soumyananda Dinda, Sidho-Kanho-Birsha University, India

This chapter attempts to correlate different economic issues like inequality, poverty, green infrastructure and international trade with human health in the context of climate change. In this short survey not only we have tried to capture most of the relevant articles in the corresponding category, but also we have shouted for some of the major research gaps in the form of future research agenda. Interestingly from our short survey we have found that importance of developing as well as less developed economies have been neglected in the context of climate change.

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Sukanya Das, TERI University, India

Human health is heavily dependent on clean water resources and adequate sanitation. According to the WHO, diarrhoea is the disease most attributable to quality of the local environment. It has been estimated that 88% of diarrhoea cases result from the combination of unsafe drinking water, inadequate sanitation, and improper hygiene. A meta-analysis has been conducted over the existing literature specifically targeting water-borne and water-related diseases in developing countries. The results are synthesized through the simplest meta-analysis strategy: vote-counting. Given the range of impacts on account of climate change there is an urgent need of proper intervention to counterbalance the expected increase of occurence of water-related illness But given the limited progress in reducing incidences over the past decade consorted actions effective implementation and integration of existing policies is urgently demanded.

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Joydeep Majumder, National Institute of Occupational Health, India
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Sunil Kumar, National Institute of Occupational Health, India

The average global temperature increase is estimated to go up by 1.8-4.0 0C by the next century. This climate change ought to affect populations where the burden of climate-sensitive disease is high – such as the urban poor in low- and middle-income countries. Particularly in industrial applications, heat generates during manufacturing process. This heat transmits to the environment to make it hotter, as well as the community, especially affecting workers involved in the operation. The primary outcomes of working in such environment leads to three kinds of major heat-related disorders-heat cramps, heat exhaustion and heat stroke. Understanding the quantifiable volume of health impacts due to work habits in hot working environment would provide multiple avenues of suitable intervention. Elucidating the multiple avenues of work pattern, physical and physiological attributes would generate knowledgebase and yield numerically defined susceptibility limits of workers occupational front. The present chapter provides directions to research into the heat related health profile of Indian workmen which would ascertain the relative vulnerability of different occupational groups to their workplace heat eventuality.

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Sibananda Senapati, Chandragupt Institute of Management Patna (CIMP), India
Vijaya Gupta, National Institute of Industrial Engineering (NITIE), India

This paper is based on a detail review of literature available in the area of climate change, vulnerability and impact assessment. Methodological issues pertaining to vulnerability like; development of vulnerability indicators, process of indicator selection etc are the main focus in this paper. As discussed indicators are more acceptable, easy to understand and help in comparing across regions. However, indicators also possess a number of limitations. There are issues in selecting indicators and how to aggregate their values. The current study tries to overcome those issues through a primary study. The study region is Mumbai, India and 'Koli' fishing communities reside in the city. The socio-economic implications of climate change and vulnerability of communities depending on fishery are estimated by developing vulnerability indicators using Sustainable Livelihood Approach (SLA), and Analytic Hierarchy Process (AHP). Further experts opinions are considered while selecting indicators. Vulnerability indicators are derived from literature and validated through experts' opinion. Experts are chosen from higher learning institutes in the city. In the climate change literature vulnerability mainly divided into exposure, sensitivity and adaptive capacity. The indicators of sensitivity and exposure under vulnerability are combined here and categorized into two: livelihood and perceived changes. Similarly the indicators of adaptive capacity are of five categories comprising human, physical, financial, social and government policy related indicators. Thus a total 30 indicators are selected. Among five fishing villages surveyed, fishermen from Madh and Worli are found more vulnerable because of their high sensitivity and low adaptive capacity. The derived vulnerability scores are further compared and analyzed against the scores derived from experts. The overall result shows the experts value of indicators are similar with the indicator score derived in the study using simple aggregate method. This study further provides policy implications for reducing vulnerability of fishing villages.

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Ahmed Karmaoui, Independent Researcher, Morocco

The Mediterranean basin (MB) connects the south with the north and the East (Europe, Africa & Asia). It is a highly heterogeneous region where natural and anthropogenic activities interact in complex ways with climate variability. Climate change (CC) impacts are already defined on the Mediterranean. That is why the time has come to formulate a long-term plan for adaptation to CC of the MB. In this chapter the author aims (i) the assessment of the environmental vulnerability under CC provided in the BM during the last 30 years, (ii) the determination of environmental vulnerability indicators that the author call Major Common Indicators (MCI), and (iii) identification of adaptation strategies based on these indicators. For this analysis the author used the results of the Environmental Vulnerability Index (EVI), developed by SOPAC. In this paper, the author extracted, compiled, compared and analyzed the data of the EVI of 8 selected Mediterranean countries; 4 countries in North Africa (Morocco, Algeria, Tunisia and Egypt) and 4 Southern Europe (Spain, France, Italy and Greece).

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Mrutyunjay Swain, Sardar Patel University, India

The paper analyses the perceptions of the farmers on various aspects of present as well as future vulnerability to local climate change in western Odisha, India. The changes in various climatic factors like rainfall, temperature, drought frequency and intensity during last three decades have been assessed. The farmers' experiences on hardships faced, natural and human induced causes of the changes observed have been examined. The perceptions on changes/trend in various vulnerability factors such as water availability, soil quality, early warning system, deforestation, social safety nets, institutional support system, degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species etc. have been scrutinized. Besides, the future vulnerability to climate change has been assessed by ranking the vulnerability factors (economic/environmental/social/institutional) with respect to their effects during past, present and future climatic risks in the matrix form, thereby identifying the vulnerability factors posing greater threat in future. The study is based on the survey of 139 households. The study finds significant changes in behavior of climatic factors in western Odisha. The factors that are posing greater threat in future are increasing temperature and rainfall variability, frequent pest attack and plant diseases, gradual decline in grazing land and fodder availability, reduction and degradation of wild life habitat and loss of wetland and water bodies.

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P. K. Viswanathan, Gujarat Institute of Development Research (GIDR), India

The reported economic losses due to natural disasters show an increasing trend over time for India. This is due to the influence of three factors: bio-physical drivers, exposure and vulnerability. Normalising the influence of exposure and vulnerability of socio-economic factors, this chapter potentially detects the influence of climate, caused by natural climate variability as well as anthropogenic climate change, in determining the damages from natural disasters. It analyses the trends in both the reported and normalised economic losses from natural disasters in India during 1964 and 2012. Similar analysis is also carried out for a subset of major disaster events like cyclonic storms and floods. No significant trend is found either for the normalised damage costs from natural disasters or for individual extreme events like floods and cyclonic storms. The findings suggest that the increases in damage costs is due to higher exposure and vulnerability of the socio-economic conditions of those affected, and recommends for additional investments on infrastructure to strengthen the adaptive capacity of the vulnerable sections with respect to the socio-economic factors.

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Mrutyunjay Swain, Sardar Patel University, India
Mamata Swain, Ravenshaw University, India

The paper analyses the major role played by the institutional support system such as government safety nets, non-governmental and community based insurance mechanism in strengthening the coping capacity of rural households facing recurrent drought in Bolangir district of western Odisha. The gradual refinement of drought management policies and the role played by centre-state relationship and power equations in implementation of programmes for effective drought management have been critically examined. In addition to analysis of secondary data and literature, the primary survey data on 139 households have been analyzed to assess the role of institutional support system in building up their resilience. The institutional support system was found to be weak to withstand drought in effective manner in the study region. A gradual improvement to the drought management policies was observed and every major drought resulted in some qualitative improvement to the relief approach. However, the implementation of the development schemes was affected by the power politics.

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C. P. Kumar, National Institute of Hydrology, India

Climate change poses uncertainties to the supply and management of water resources. While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels, and saline intrusion in coastal aquifers due to sea level rise and resource reduction. This chapter presents the likely impact of climate change on groundwater resources and methodology to assess the impact of climate change on groundwater resources.

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Seema Rani, CSRD, Jawaharlal Nehru University, India

Climate change is one of the very significant apprehension argued in the recent two decades. Its influence on rainfall has brought in considerable attention worldwide. Hence, this chapter focuses on assessing the trends in the rainfall during 1901-2012 in the Dehradun, Haridwar, Uttarkashi, Tehri-Garhwal, Pauri-Garhwal, Rudraprayag and Chamoli districts of the Garhwal Himalayas by applying non-parametric Mann-Kendall and the Theil-Sen's Slope Estimator tests for the determination of trend and its magnitude. The findings revealed a statistically significant positive trend in annual and monthly rainfall (May and July) of Dehradun district. Rainfall shows a statistically significant positive trend in May (Haridwar and

Tehri Garhwal) and a significant negative trend in January (Uttarkashi and Chamoli). On the other hand, Pauri Garhwal and Rudraprayag indicates no significant trend in monthly rainfall. An insignificant trend has also been observed in seasonal rainfall of most of the districts. Annual, monthly and seasonal rainfall shown no particular pattern in the region.

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Sibananda Senapati, Chandragupt Institute of Management Patna, India
Vijaya Gupta, National Institute of Industrial Engineering, India

This paper attempts to understand the climatic and socio-economic factors influencing the efficiency and thereby the livelihood of fishing community in Mumbai. Efficiency in fishing is influenced by the scale of production, technology and inputs used, socio-economic and climate sensitive factors such as temperature, current, wind, rainfall etc. A primary survey of 164 fishing households is conducted in five fishing villages of Mumbai to collect input-output and other relevant data related to socioeconomic and climatic factors. Using stochastic frontier function, it is found that the number of working days, fuel costs, number of workers along with type of family, education, electronic gadgets used in fishing and observation on temperature change significantly affects the productivity and thereby their preparedness. The fishermen belonging to nuclear family and using advanced fishing equipments along with those are observing a rise in temperature successfully adapted and their efficiency level is increased. Mostly rich and affluent fishermen are more efficient than others. The estimated technical efficiencies for the fishing households range from 0.12 to 0.87, with a mean efficiency level of 0.39. Technological advancement in the production process with large scale of operation significantly influences fishermen's awareness, adaptability to climate change and also the efficiency.

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Anita Chattopadhyay Gupta, Muralidhar Girls' College, India

Coastal areas are also important ecologically, as they provide a number of environmental goods and services. Potentially, if managed sustainably, they can provide continuing returns without any decrease in their productivity. But, the unfolding state of coastal ecosystems, from the standpoint of fisheries production, is causing concern. A move towards fishing management that conserves biodiversity, permits sustainable utilization and recognizes the importance of species interaction is worthwhile. Recent recognition of such interactions in fishing has resulted in calls for adoption of ecosystem approaches to fishery management to rebuild and sustain populations, species and biological communities at high levels of productivity and biological diversity. The coupling of fishery management issues more directly with the issues of marine pollution, and biodiversity represents an increasing understanding of the linkages among them. This calls for changing fishery management paradigms towards a more coherent ecosystem approach.

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Huynh Viet Khai, Can Tho University, Vietnam

Measuring the biodiversity value in monetary could be useful information for policy-makers to estimate welfare losses caused by biodiversity reductions and perform cost-benefit analysis of biodiversity conservation projects. This study applied the approach of contingent valuation to analyze the Mekong Delta urban households' preferences and their willingness to pay for the program of biodiversity conservation in U Minh Thuong National Park, one of the largest peat swamp forests in Vietnam. The study estimated that the mean WTP of urban residents in the Mekong Delta was about VND16,510 ($0.78) per household per month for all respondents and around VND31,520 ($1.49) after excluding the protest zero and scenario rejecting respondents. Aggregately, they agreed to contribute about $10.97 million annually for the project of biodiversity conservation.

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Jayita Bit, Calcutta Business School, India
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This paper assesses the prospect of sustainable forest management (SFM) for an emerging economy like India, where forest coverage has gone up over the last three decades in spite of population growth, rapid urbanization and fast economic growth. To assess the possibility of sustainable future growth in a globally congenial environment, the extent of ecological stress on Indian economy has been assessed by using Input-Output transaction tables and pattern of expenditure by the Government and the Private sector along with Import and Export of forestry and related products over 1993-94 to 2007-08. The change in direct forest intensity (DFI) in gross domestic product has been calculated and decomposed into effects due to material intensity, structural change and economic growth. The results reveal increasing dominance of economic growth over other effects indicating necessity of designing intervention to decouple potential future economic growth from forest resources to ensure long run sustainability.

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Albert Arhin, University of Cambridge, UK

The mechanism of Reducing Emissions from Deforestation and Degradation plus conservation, sustainable forest management and enhancement of carbon stocks is emerging as one of the current efforts and actions being developed by the international climate change community to mitigate climate change. This chapter highlights the potentials as well as the challenges of this mechanism to reduce forest loss and improve the health and sustainability of the environment. Main potentials include its resolve to make trees worth more standing than cut, the transfer of funds to support conservation efforts and a focus on delivering social benefits. The main challenges include the less attention on unclear tenure and benefit-sharing framework; weak institutions and the complex historical, political and structural interests which have allowed powerful groups to expropriate the forest resources and trade-offs that may arise during implementation. It then outlines four broad areas where researchers can make contributions in national and local level policy-making and interventions related to REDD+.

Section 7
Land and Adaptation

Chapter 17
Lack of Land Tenure Security as Challenges to Sustainable Development: An Assessment in the Context of Bihar, India 348
Debabrata Samanta, Chandragupt Institute of Management Patna, India

Tenural security towards land has far-reaching and long lasting socio-economic implications. Secured tenural right over land found as influencing factor in utilising the land in more efficient way, do investment as well as precondition for environmentally sustainable natural resource use. Though there are numerous laws have been initiated in Bihar to ensure land right and equity in distribution, but their implementation to ensure land tenure security is a far cry. The lack of tenural right, theoretically, paves way for two problems towards sustainable development; in one hand it restrict the sharecropper to undertake a long term investment in the land to increase productivity, on the other hand this might have created the problem termed as 'tragedy of commons'. The study made an assessment of the legal framework and argues for proper legal initiative and effective implementation to protect land tenure security for sustainable development.

Chapter 18
Adaptation to Climate Change for Sustainable Development: A Survey 363
Soumyananda Dinda, Sidho-Kanho-Birsha University, India

Climate change is an important global issue. For sustainable development human society must adopt the climate change and reduce vulnerability. This chapter provides an overview on the climate change and its effects, in response how human societies adopt it across the globe. Chapter reviews major papers on adaptation to climate change. Based on major important articles this chapter provides clarity of the concept of adaptation, types of adaptation, measurement of adaptation and determinants of adaptive capacity. It also highlights on sustainable development and shows possible future directions of adaptation and limitations.

Section 8
Agriculture

Chapter 19
Climate Change and Agriculture: Impacts, Adoption, and Mitigation 393
Sunil Lalasaheb Londhe, Centre for Development of Advanced Computing, India

Increasing evidence shows that shifts in Earth's climate have already occurred and indicates that changes will continue in the coming years. This chapter is an attempt to distil what is known about the likely effects of climate change on food security and nutrition in coming decades. Apart from few exceptions, the likely impacts of climate change on agricultural sector in the future are not understood in any great

depth. There are many uncertainties as to how changes in temperature, rainfall and atmospheric carbon dioxide concentrations will interact in relation to agricultural productivity. The consequences of climate change on various important aspects of agriculture such as crop production, livestock, availability of water, pest and diseases etc. are discussed and summarized. Each of this aspect of agriculture sector will have certain impact which may be positive or negative. The chapter also discusses on the possible mitigation measures and adaptations for agriculture production in the future climate change scenarios.

Chapter 20
Impact of Rapid Urbanization and Climate Change on Agricultural Productivity in Africa: Climate Change Policies in the Agricultural Sector 416
Mutisya Emmanuel, University of Tokyo, Japan
Lilian Muasa, University of Tokyo, Japan
Chiahsin Chen, University of Tokyo, Japan
Florence Mutisya, London South Bank University, UK
Ram Avtar, United Nations University, Japan

Africa continues to experience serious signs of multiple crises in the context of sustainability. These crises include vulnerability to climate change, rapid urbanization, food insecurity, and many others. One crisis, that defines Africa today, is the unprecedented rapid urbanization which continues to pose a big challenge to the diminishing available resources, environmental quality and human well-being. Cities in Africa continue to experience a fast horizontal growth of settlements due to influx of people from rural areas who often settle in the economically lowest segments in urban areas. This horizontal rapid growth has eaten up land set for agriculture around cities and promoted the rapid growth of informal settlements exacerbating the impacts of climate change leading to a negative impact on agricultural production. Policies linking rapid urbanization and climate change with agricultural productivity are need. This paper explores and documents the impact of rapid urbanization on climate change policies and subsequent impact on agriculture in Africa.

Chapter 21
Climate Change Mitigation: Collective Efforts and Responsibly 427
Nishi Srivastava, Birla Institute of Technology, India

Climate change caused due to our careless activities towards our nature, ecosystem, and whole earth system. We are paying and will be paying in future for our irresponsible activities in past and present. Increased concentration of Green House Gases (GHG) has caused severe global warming which will cause melting of glacier and results in sea level rise. To avoid and reduce the intensity and severity of global warming and climate change, its mitigation is essential. In this chapter we have focused on various issues related with climate change and mitigation strategies.

Section 9
Adaptive Capability

Chapter 22
Coastal Poverty, Resource-Dependent Livelihood, Climate Change, and Adaptation: An Empirical Study in Indian Coastal Sunderbans 441
Jyotish Prakash Basu, West Bengal State University, India

Millions of people in Sunderbans generate their livelihood and sustenance through fishing, honey collection, fuel wood and timber. The paper attempts to examine the issues of coastal poverty, food security as well as livelihood insecurity and the adaptation options that help to the resilience of climate change. The paper is based on field survey conducted in the villages of Sunderans in 2011. The study revealed that fishing and crab collection, honey collection are the important sources of livelihood. The fishing resources have been declining which leads to the insecurity of livelihoods of the fishing communities. The study has identified the key adaptations like dependency of money lenders, fishing and crab collection, formation of Self Help Groups, livestock rearing and migration. This paper has important policy implications for poverty, livelihood vulnerability and migration.

Chapter 23
Climate Change and Adaptation through the Lens of Capability Approach: A Case Study from Darjeeling, Eastern Himalaya 455
Bhupen Mili, Indian Institute of Technology Guwahati, India
Anamika Barua, Indian Institute of Technology Guwahati, India
Suparana Katyaini, Indian Institute of Technology Guwahati, India

Climate Change impacts would disproportionately have larger impacts on the developing countries. Both government and development agencies have initiated various adaptation strategies in the developing countries to enhance the adaptation of the local communities. Various policies and programmes have been designed keeping in mind the impact of climate change. This study was conducted in Darjeeling district of West Bengal, India, to see the benefits of such policies and programmes. Focus group discussion with community members were held in the study area. Based on the fieldwork it was seen that most of the intervention made in the study area focused on income, resources, and assets. It has failed to benefits the people due to variation in the capability among various section of the society. Various projects related to health, education, housing, and livelihood, have been implemented in the study region. However, due to lack of conversion factors in the form of gender inequality, discriminatory practices, transparency among others have come as a hindrance in the successful implementation of the projects. Hence, such project-based approach to enhance community's adaptation to climate risk, in the end fails to show benefits as it fails to expand community's capabilities and real freedom, due to the project's pre-defined aims. It is important to understand community's as agent of change rather than merely beneficiaries of adaptation projects. This study therefore recommends that to enhance community's adaptation to climate change, the interventions should be such that it enlarges the range of people's choices so that when climate disaster strikes them they will have a set of opportunities.

Section 10
Industry

Chapter 24
A Framework for Understanding Adaptation by Manufacturing Industries 471
Saon Ray, ICRIER, India

This chapter discusses what constitutes adaptation responses by firms in the face of climate change. There are four integral components of adaptation activities undertaken by firms: assessment of risk, understanding of vulnerability, understanding the regulatory barriers to overcome the vulnerability, and, finally, adoption of policies to overcome the vulnerability. While it is easy to understand these components separately, their interdependencies make the overall picture more complicated. Also complicating the issue is the fact that most small and medium firms do not have the capacity and resources to predict the impact of such changes on their operations, and hence, to quickly make the adjustments necessary to overcome them. The response of firms also depends on the nature of the climate risk they face, whether it is sea-level rise, or temperature rise.

Chapter 25
Temporal Data Analysis and Mining Methods for Modelling the Climate Change Effects on Malaysia's Oil Palm Yield at Different Regional Scales 482
Subana Shanmuganathan, Auckland University of Technology, New Zealand
Ajit Narayanan, Auckland University of Technology, New Zealand
Nishantha Priyanka Kumara Medagoda, Auckland University of Technology, New Zealand

Space and time related data generated is becoming ever more voluminous, noisy and heterogeneous outpacing the research efforts in the domain of climate. Nevertheless, this data portrays recent climate/weather change patterns. Thus, insightful approaches are required to overcome the challenges when handling the so called "big data" to unravel the recent unprecedented climate change in particular, its variability, frequency and effects on key crops. Contemporary climate-crop models developed at least two decades ago are found to be unsuitable for analysing complex climate/weather data retrospectively. In this context, the chapter looks at the use of scalable time series analysis, namely ARIMA (Autoregressive integrated moving average) models and data mining techniques to extract new knowledge on the climate change effects on Malaysia's oil palm yield at the regional and administrative divisional scales. The results reveal recent trends and patterns in climate change and its effects on oil palm yield impossible otherwise e.g. Traditional statistical methods alone.

Section 11
Trade

Chapter 26
Climate Change, Trade Competitiveness, and Opportunity for Climate Friendly Goods in SAARC and Asia Pacific Regions... 515
Soumyananda Dinda, Sidho Kanho Birsha University, India

This paper examines trade performance of climate friendly goods using some trade indices for South Asia and Asia Pacific countries during 2002 - 2008. Climate friendly goods (CFG) are those goods which are less harmful to environment. Paper identifies performance of Asia Pacific region in CFG trade with other nations. Most of the countries in Asia are importers of climate friendly goods and technologies. The

Comparative advantage analyses indicate that Hong Kong, China, and Japan have comparative advantage in the production of CFG goods. Pakistan, Sri-Lanka, and India prefer to trade in CFG regionally and have shown interest in production and trade of clean coal technologies (CCT). East and South East Asia regions have comparative advantage in Solar Photovoltaic Systems (SPVS) and Energy Efficient Lighting (EEL). Japan, China, Malaysia and Macao show good in 2008 for SPVS.

Chapter 27
Greenhouse Gas Mitigation through Energy Efficiency: Perform, Achieve, and Trade (PAT) – India's Emission Trading Scheme 537
Ali Reja Osmani, Karimganj Law College, India

Pursuant to the Thirteenth Conference of Parties to the UNFCCC held at Bali in 2007, based on Nationally Appropriate Mitigation Action plan, India has introduced its very own Emission Trading Scheme (ETS) called Perform, Achieve and Trade (PAT) market mechanism. The country has already achieved remarkable success in the renewable energy front. This chapter studied the existing policy regime of renewable energy and energy efficiency, and tried to understand how far the country practically can achieve the objective enshrined by PAT mechanism. This paper highlighted the background of the market based ETS, where various policies and legislation were put in place to provide energy efficient service and energy efficient system to the large energy intensive sectors of Indian economy. However it is not conducive to come to a conclusion regarding PAT's success or failure unless the First PAT cycle is completed, i.e. 2012-13 to 2014-15 compliance period is over.

Section 12
Policy and Innovation

Chapter 28
Does Fiscal Policy Influence Per Capita CO2 Emission? A Cross Country Empirical Analysis 568
Sacchidananda Mukherjee, National Institute of Public Finance and Policy (NIPFP), India
Debashis Chakraborty, Indian Institute of Foreign Trade (IIFT), India

Encouraging economic activities is a major motivation for countries to disburse subsidies, but such transfers may also lead to sustainability and climate change related concerns. Through a cross-country empirical analysis involving 131 countries over 1990-2010, the present analysis observes that higher proportional devolution of budgetary subsidies lead to higher CO2 emissions. The results demonstrate that structure of economy is a crucial determinant for per capita CO2 emission, as countries having higher share in agriculture and services in GDP are characterized by lower per capita CO2 emission and vice versa. The empirical findings also underline the importance of the type of government subsidy devolution on CO2 emissions. Countries having high tax-GDP ratio are marked by lower per capita CO2 emission, implying that government budgetary subsidy is detrimental for environment whereas tax is conducive for sustainability. The analysis underlines the importance of limiting devolution of subsidies both in developed and developing countries.

Chapter 29
Social Innovation: A Theoretical Approach in Intertwining Climate Change with Social Innovation 593
Sayan Banerjee, Chandragupt Institute of Management Patna, India

In this paper an attempt has been made to link the understanding relating to innovation in organisations with that of societal innovation at large which was later on extended to summarise the literature of social innovation and climate change. The organisation forms part of (and exists in) the social system. From the view point of organisational studies the social system may be seen as consisting of two levels while the immediate vicinity of the organisation encompasses the various organisational stakeholders and correlates the second level pertains to society in general. According to Savvides (1979), the second level encompasses the first which in turn encompasses the organisation. In this paper a comprehensive review has been presented for a better understanding of social innovation its correlation with climate change through the concepts used to understand organisational innovation.

Chapter 30
Moving forward a Parsimonious Model of Eco-Innovation: Results from a Content Analysis.......... 619
Yudi Fernando, Universiti Sains Malaysia, Malaysia
Wen Xin Wah, Universiti Sains Malaysia, Malaysia

Complexity of sustainability issue in operations management leads this study to determine a parsimonious model of eco-innovation. Most of research findings have been emphasized on the effect of innovation on company's economic benefits. However, there is inadequate study in respect to eco-innovation and impact to business and environmental sustainability. This is causing a lack of study on this topic. The paper focuses on determinants of drivers of eco-innovation and seeks the impact to the outcome of sustainable business performance. Content analysis is used in order to explain phenomena of eco-innovation in operations management and categorize the determinants of drivers. The unit of analysis of this study is driver or factor of eco-innovation which commonly uses in entire articles. The scope of review encompassed articles published during 1994 to 2012. Results indicate that a parsimonious model of eco-innovation was consisted of five drivers. More comprehensive and robust findings could be obtained by testing this model and broadening the scope of study.

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Preface

Climate change is an important global issue. Globally, in the past century, temperature has increased about 0.6^0 C, sea level has risen nearly 20 cm – it is partly due to melting of mountain ice and partly due to thermal expansion of the oceans. Scientific research finds evidences that in last two centuries anthropogenic activities have increased atmospheric greenhouse gases concentration that is more than pre-industrial levels. Recent climate change is the result of human actions and specially from the burning of fossil fuels and land use changes. Development activities increase the atmospheric concentrations of greenhouse gases (GHG) – mainly carbon dioxide, methane and nitrous oxide. The GHGs are accumulated in the upper level of atmosphere which is tapping solar long-wave radiation that raises temperature. It also provokes other forms of climate disruption and accelerates the process. This depends on a complex interplay of many factors, including rates of population expansion, economic growth and patterns of consumption. The changes differ from one location to another. There are different weather consequences, while some regions have intense rainfall, others have more prolonged dry period and few areas have both. As a consequence of continued global warming, billions and billions of people around the World are facing risk of flooding, droughts and debilitating diseases like Malaria, Dengue, etc. Poor people in under developed nations are likely to be most vulnerable in health and their livelihoods. The social consequences also vary as per level of development.

Truly, climate change is one of the greatest threats to the human civilization and the toughest challenge for economic development in this twenty-first century. The scientific community of developed countries warns the world leaders regarding the threat of climate change and warns about its inevitable impact on human society. In this context, several questions arise: How do we measure the impact of climate change on human society? What is the impact on the economy? Is there any empirical evidence? How do we assess the climate change impacts and adaptive capacity in human society in different scales? More specifically, how do we adapt and mitigate climate change recently in global as well as local level? To assess the climate change a multidimensional study is required engaging several experts and producing one handbook explicitly focusing on climate change and related issues – mainly assessment, adaptation and mitigation.

This Handbook provides extensive scientific evidences on climate change covering Mountain region to Coastal area, and local environmental issues to national problems to the Global issues. The handbook provides the world community with the most up-to-date and comprehensive scientific, technical, and socio-economic information about climate change impact assessment, adaptation and mitigations in the world. This handbook investigates number of climate change related issues which help to clarify currently the world position on global warming and climate change. It identifies major issues related to climate change on health and environmental sustainability focusing on impact measurements, policy, adaptation and mitigation in the world as well as national or regional and local level.

Main objective of this handbook is to improve the understanding of scientific analysis and promoting evidence based policy formulation in the global, regional and local levels. The themes are covered in this handbook including scientific knowledge and its application in different scales, and also focus on issues of relevance for local, national and global policy, strategy for addressing emerging global and national development concerns.

Key topics covered include the issues, social and political reception of climate science, the denial of that science by individuals and organized interests, the nature of the social disruptions caused by climate change, the economics of those disruptions and possible responses to them, questions of human security and social justice, obligations to future generations, policy instruments for reducing greenhouse gas emissions, and governance at local, regional, national, international, and global levels.

The handbook of research on climate change and sustainable development is a research compilation of global climate change. Scientists and academicians, from different parts of the world, have contributed in this handbook. The book provides a collection of viewpoints and information. The handbook of research discusses the challenges brought about by the need to adapt to a changing climate. This handbook combines the strengths of an interdisciplinary team of experts from around the world to explore current debates and the latest thinking in the search for climate change solutions. This handbook is a collaborative effort of distinguished experts from around the world and adopts a holistic approach to adaptation, taking a global view, with a focus on the international, the regional and domestic levels.

This comprehensive book covers a wide range of research areas, including: Socio-Economic Scenarios, Assessment, Adaptation and Mitigation to Climate Change – Impact Assessment, Human Health, Vulnerability, Natural Disaster, Water Resources, Coastal Zones, Agriculture, Forest, Fisheries, etc. This handbook has two major parts: One) Assessment and, Two) Adaptation and Mitigation. Each part has several sections containing different chapters. Assessment part highlights the impact of climate change on major human and natural resources. Part one has been divided into seven sections such as Health, Vulnerability, Natural Disaster, Water, Fishery, Forestry and Land. Adaptation and mitigation part focuses on adaptation mechanism and mitigating policies. Part two contains a survey on adaptation to climate change for sustainable development and five major sections such as Agriculture, Adaptive capacity, Industry, Trade, Policy and Social Innovation. Handbook is rich in contents and covers major intersection of research areas of science and application with socio-economic and bio-economic aspects. Basically, part one is the assessment of impact of climate change and part two provides the way to find solutions.

This handbook provides insight into the global climate change and related socio-economic issues especially focusing on climate change impacts on natural resources, human health and adaptive capability. This handbook has covered different critical aspects of global, regional and local climate change, such as assessment, adaptation and mitigation, and over all sustainable development issues. This handbook is a comprehensive and timely analysis of various aspects of climate change and its consequences that aim to be an essential reference source built on the available literature. Now, briefly I overview the topics included in this handbook.

Chapter one investigates the rising health risks in India due to climate change and suggests to improve health service. It is true that climate change is expected to exacerbate human health risks but, simultaneously, provide excellent opportunity for preventive actions. Developing nations like India, with low infrastructure facilities, limited resources, and varied development priorities and, often with large population, are particularly vulnerable to health impacts - more so under the climate change regime. The greatest challenge facing the current Indian health service provisioning system is that it has to cater to the health service needs of its large population within a short time and with sustainable impact. Limited health *cure infrastructure* (low per capita availability of doctor, hospital beds, etc.), lack of qualified health practitioners, absence of a strong monitoring system in disease surveillance and rising cost of *cure infrastructure* are some of the major drawbacks of the existing system in India. There is, therefore, a need for mainstreaming more preventive measures which enhance human health resilience and make the population less exposed, and with more adaptive capacity to predicted long term consequences. To provide preventive care to the Indian population, a paradigm shift in strategy is required. The new regime needs to emphasize on an integration of *traditional preventive health care systems* with modern cure targeted pharmaceuticals and non-health sector interventions. Such a holistic system is expected to reduce need for cure and will be inclusive in nature.

Chapter two attempts to correlate different economic issues like inequality, poverty, green infrastructure and international trade with human health in the context of climate change. In this short survey not only we have tried to capture most of the relevant articles in the corresponding category, but also we have shouted for some of the major research gaps in the form of future research agenda. Interestingly from our short survey we have found that importance of developing as well as less developed economies have been neglected in the context of climate change.

Chapter three reviews health impact of water related diseases in South Asia. Human health is heavily dependent on clean water resources and adequate sanitation. According to the WHO, diarrhoea is the disease most attributable to quality of the local environment. It is estimated that 88% of diarrhoea cases result from the combination of unsafe drinking water, inadequate sanitation, and improper hygiene. This chapter analyses the existing literature specifically targeting water-borne and water-related diseases in developing countries. The results are synthesized through the simplest meta-analysis strategy: vote-counting. The existing study cover all peer review journal studies, white and grey literature on the health impacts of water pollution of developing countries. Given the range of impacts on account of climate change there is an urgent need of proper intervention have the potential to counterbalance the expected increase of more than 10%. But given the limited progress in reducing incidences over the past decade consorted actions and effective implementation and integration of existing policies is needed.

Chapter four presents working environment in industry. They motivate for further research on it and proper direction of research. Climate change ought to affect populations, particularly in industrialization, heat generates during manufacturing process. This heat transmits to the environment to make it hotter, as well as the community, especially affecting workers involved in the operation. Primary outcomes of working in hot environment are three major heat-related disorders: (i) heat cramps, (ii) exhaustion and (iii) stroke. Understanding the quantifiable volume of health impacts due to work habits in hot working environment would provide multiple avenues of suitable intervention. Control of heat may have several advantages in terms of better health, improved productivity, lower rates of accident and morbidity. Elucidating the multiple avenues of work pattern, physical and physiological attributes would yield numerically defined susceptibility limits of workers occupational front. The present chapter provides directions to research into the heat related health profile of Indian workmen which would ascertain the relative vulnerability of different occupational groups to their workplace heat eventuality.

Chapter five reviews literature on climate change, vulnerability and impact assessment. He covers mainly methodological issues pertaining to vulnerability like; development of vulnerability indicators, process of indicator selection etc. As discussed indicators are more acceptable, easy to understand and help in comparing across regions. However, indicators also possess a number of limitations. There are issues in selecting indicators and how to aggregate their values. He tries to overcome those issues through a primary study. The study region is Mumbai, India and 'Koli' fishing communities reside in the city. The socio-economic implications of climate change and vulnerability of communities depending on fishery are estimated by developing vulnerability indicators using Sustainable Livelihood Approach (SLA), and Analytic Hierarchy Process (AHP). Further experts opinions are considered while selecting indicators. Vulnerability indicators are derived from literature and validated through experts' opinion. Experts are chosen from higher learning institutes in the city. In the climate change literature vulnerability mainly divided into exposure, sensitivity and adaptive capacity. The indicators of sensitivity and exposure under vulnerability are combined here and categorized into two: livelihood and perceived changes. Similarly the indicators of adaptive capacity are of five categories comprising human, physical, financial, social and government policy related indicators. Thus a total 30 indicators are selected. Among five fishing villages surveyed, fishermen from Madh and Worli are found more vulnerable because of their high sensitivity and low adaptive capacity. The derived vulnerability scores are further compared and analyzed against the scores derived from experts. The overall result shows the experts value of indicators are similar with the indicator score derived in the study using simple aggregate method. This study further provides policy implications for reducing vulnerability of fishing villages.

Chapter six investigates environmental vulnerability indicators and adaptation strategy. The Mediterranean basin (MB) connects the south with the north and the East (Europe, Africa & Asia).It is a highly heterogeneous region where natural and anthropogenic activities interact in complex ways with climate variability. Climate change (CC) impacts are already defined on the Mediterranean. That is why the time has come to formulate a long-term plan for adaptation to CC of the MB. In this chapter the author aims (i) the assessment of the environmental vulnerability under CC provided in the BM during the last 30 years, (ii) the determination of environmental vulnerability indicators that the author call Major Common Indicators (MCI), and (ii) identification of adaptation strategies based on these indicators. For this analysis the author used the results of the Environmental Vulnerability Index (EVI), developed by SOPAC. In this paper the author extracted, compiled, compared and analyzed the data of the EVI of 8 selected Mediterranean countries; 4 countries in North Africa (Morocco, Algeria, Tunisia and Egypt) and 4 Southern Europe (Spain, France, Italy and Greece).

Chapter seven analyses the perceptions of the farmers on various aspects of present as well as future vulnerability to local climate change in western Odisha, India. The changes in various climatic factors like rainfall, temperature, drought frequency and intensity during last three decades have been assessed. The farmers' experiences on hardships faced, natural and human induced causes of the changes observed have been examined. The perceptions on changes/trend in various vulnerability factors such as water availability, soil quality, early warning system, deforestation, social safety nets, institutional support system, degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species etc. have been scrutinized. Besides, the future vulnerability to climate change has been assessed by ranking the vulnerability factors (economic/environmental/social/institutional) with respect to their effects during past, present and future climatic risks in the matrix form, thereby identifying the vulnerability factors posing greater threat in future. The study is based on the survey of 139 households. The study finds significant changes in behavior of climatic factors in western Odisha. The factors that are posing greater threat in future are increasing temperature and rainfall variability, frequent pest attack and plant diseases, gradual decline in grazing land and fodder availability, reduction and degradation of wild life habitat and loss of wetland and water bodies.

Chapter eight investigates economic damages from natural disasters. The reported economic losses due to natural disasters show an increasing trend over time for India. This is due to the influence of three factors: bio-physical drivers, exposure and vulnerability. Normalising the influence of exposure and vulnerability of socio-economic factors, this chapter potentially detects the influence of climate, caused by natural climate variability as well as anthropogenic climate change, in determining the damages from natural disasters. It analyses the trends in both the reported and normalised economic losses from natural disasters in India during 1964 and 2012. Similar analysis is also carried out for a subset of major disaster events like cyclonic storms and floods. No significant trend is found either for the normalised damage costs from natural disasters or for individual extreme events like floods and cyclonic storms. The findings suggest that the increases in damage costs is due to higher exposure and vulnerability of the socio-economic conditions of those affected, and recommends for additional investments on infrastructure to strengthen the adaptive capacity of the vulnerable sections with respect to the socio-economic factors.

Chapter nine examines the evolution of drought management policies and programmes and their effectiveness with a special focus on management of severe drought of 2002 in western Odisha, India. The role played by centre-state relationship and power equations in implementation of drought management policies and programmes has been critically examined. The study is based on the literature reviews, secondary data analysis and the findings of a field survey of 139 households. The study finds that the institutional support system in the region is not very much effective in management of drought risk. Though a gradual improvement in drought management policies and programmes was observed and every major drought induced some qualitative improvement to the relief approach, the nature of centre-state relationship and influence of pressure groups play key role in the sanction of funds and implementation of the development schemes.

Chapter ten highlights impact of climate change on ground water resource. Climate change poses uncertainties to the supply and management of water resources. While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels, and saline intrusion in coastal aquifers due to sea level rise and resource reduction. This chapter presents the likely impact of climate change on groundwater resources and methodology to assess the impact of climate change on groundwater resources.

Chapter eleven assesses the rainfall overtime in the Harwal Himalayas. Climate change is one of the very significant apprehension argued in the recent two decades. Its influence on rainfall has brought in considerable attention worldwide. Hence, this chapter focuses on assessing the trends in the rainfall during 1901-2012 in the Dehradun, Haridwar, Uttarkashi, Tehri-Garhwal, Pauri-Garhwal, Rudraprayag and Chamoli districts of the Garhwal Himalayas by applying non-parametric Mann-Kendall and the Theil-Sen's Slope Estimator tests for the determination of trend and its magnitude. The findings revealed a statistically significant positive trend in annual and monthly rainfall (May and July) of Dehradun district. Rainfall shows a statistically significant positive trend in May (Haridwar and Tehri Garhwal) and a significant negative trend in January (Uttarkashi and Chamoli). On the other hand, Pauri Garhwal and Rudraprayag indicate no significant trend in monthly rainfall. An insignificant trend has also been observed in seasonal rainfall of most of the districts. Annual, monthly and seasonal rainfall has shown no particular pattern in the region.

Chapter twelve attempts to understand the climatic and socio-economic factors influencing the efficiency and thereby the livelihood of fishing community in Mumbai. Efficiency in fishing is influenced by the scale of production, technology and inputs used, socio-economic and climate sensitive factors such as temperature, current, wind, rainfall etc. A primary survey of 164 fishing households is conducted in five fishing villages of Mumbai to collect input-output and other relevant data related to socioeconomic and climatic factors. Using stochastic frontier function, it is found that the number of working days, fuel costs, number of workers along with type of family, education, electronic gadgets used in fishing and observation on temperature change significantly affects the productivity and thereby their preparedness. The fishermen belonging to nuclear family and using advanced fishing equipments along with those are observing a rise in temperature successfully adapted and their efficiency level is increased. Mostly rich and affluent fishermen are more efficient than others. The estimated technical efficiencies for the fishing households range from 0.12 to 0.87, with a mean efficiency level of 0.39. Technological advancement in the production process with large scale of operation significantly influences fishermen's awareness, adaptability to climate change and also the efficiency.

Chapter thirteen highlights the need of the bio-economic fishery management focusing on the changing paradigms towards ecosystem based management. Coastal areas are also important ecologically, as they provide a number of environmental goods and services. Potentially, if managed sustainably, they can provide continuing returns without any decrease in their productivity. But, the unfolding state of coastal ecosystems, from the standpoint of fisheries production, is causing concern. A move towards fishing management that conserves biodiversity, permits sustainable utilization and recognizes the importance of species interaction is worthwhile. Recent recognition of such interactions in fishing has resulted in calls for adoption of ecosystem approaches to fishery management to rebuild and sustain populations, species and biological communities at high levels of productivity and biological diversity. The coupling of fishery management issues more directly with the issues of marine pollution, and biodiversity represents an increasing understanding of the linkages among them. This calls for changing fishery management paradigms towards a more coherent ecosystem approach.

Chapter fourteen estimates the economic value of Swamp forest. Measuring the biodiversity value in monetary could be useful information for policy-makers to estimate welfare losses caused by biodiversity reductions and perform cost-benefit analysis of biodiversity conservation projects. This study applied the approach of contingent valuation to analyze the Mekong Delta urban households' preferences and their willingness to pay for the program of biodiversity conservation in U Minh Thuong National Park, one of the largest peat swamp forests in Vietnam. The study estimated that the mean WTP of urban residents in the Mekong Delta was about VND16,510 ($0.78) per household per month for all respondents and around VND31,520 ($1.49) after excluding the protest zero and scenario rejecting respondents. Aggregately, they agreed to contribute about $10.97 million annually for the project of biodiversity conservation.

Chapter fifteen assesses the prospect of sustainable forest management (SFM) for an emerging economy like India, where forest coverage has gone up over the last three decades in spite of population growth, rapid urbanization and fast economic growth. To assess the possibility of sustainable future growth in a globally congenial environment, the extent of ecological stress on Indian economy has been assessed by using Input-Output transaction tables and pattern of expenditure by the Government and the Private sector along with Import and Export of forestry and related products over 1993-94 to 2007-08. The change in direct forest intensity (DFI) in gross domestic product has been calculated and decomposed into effects due to material intensity, structural change and economic growth. The results reveal increasing dominance of economic growth over other effects indicating necessity of designing intervention to decouple potential future economic growth from forest resources to ensure long run sustainability.

Chapter sixteen focuses on health of forest and critically assesses its recovery mechanism. The mechanism of Reducing Emissions from Deforestation and Degradation plus conservation, sustainable forest management and enhancement of carbon stocks is emerging as one of the current efforts and actions being developed by the international climate change community to mitigate climate change. This chapter highlights the potentials as well as the challenges of this mechanism to reduce forest loss and improve the health and sustainability of the environment. Main potentials include its resolve to make trees worth more standing than cut, the transfer of funds to support conservation efforts and a focus on delivering social benefits. The main challenges include the less attention on unclear tenure and benefit-sharing framework; weak institutions and the complex historical, political and structural interests which have allowed powerful groups to expropriate the forest resources and trade-offs that may arise during implementation. It then outlines four broad areas where researchers can make contributions in national and local level policy-making and interventions related to REDD+.

Chapter seventeen assesses land tenure security and sustainable development. Tenure security towards land has far-reaching and long lasting socio-economic implications. Secured tenure right over land found as influencing factor in utilising the land in more efficient way, do investment as well as precondition for environmentally sustainable natural resource use. Though there are numerous laws have been initiated in Bihar to ensure land right and equity in distribution, but their implementation to ensure land tenure security is a far cry. The lack of tenure right, theoretically, paves way for two problems towards sustainable development; in one hand it restrict the sharecropper to undertake a long term investment in the land to increase productivity, on the other hand this might have created the problem termed as 'tragedy of commons'. The study made an assessment of the legal framework and argues for proper legal initiative and effective implementation to protect land tenure security for sustainable development.

Chapter eighteen reviews the existing literature on adapting climate change for sustainable development. This chapter basically overviews the concept of adaptation to climate change, determining factors of adaptability, decision making agents and scale, adaptive capacity and its determinants, and highlights future adaptability from global scale to local levels, and limitations.

Chapter nineteen focuses on food security due to climate change. Increasing evidence shows that shifts in Earth's climate have already occurred and indicates that changes will continue in the coming years. This chapter is an attempt to distil what is known about the likely effects of climate change on food security and nutrition in coming decades. Apart from few exceptions, the likely impacts of climate change on agricultural sector in the future are not understood in any great depth. There are many uncertainties as to how changes in temperature, rainfall and atmospheric carbon dioxide concentrations will interact in relation to agricultural productivity. The consequences of climate change on various important aspects of agriculture such as crop production, livestock, availability of water, pest and diseases etc. are discussed and summarized. Each of this aspect of agriculture sector will have certain impact which may be positive or negative. The chapter also discusses on the possible mitigation measures and adaptations for agriculture production in the future climate change scenarios.

Chapter twenty studies the impact of rapid urbanization and climate change on agricultural productivity in Africa focusing on climate change policies in agricultural sector. Africa continues to experience serious signs of multiple crises in the context of sustainability. These crises include vulnerability to climate change, rapid urbanization, food insecurity, and many others. One crisis, that defines Africa today, is the unprecedented rapid urbanization which continues to pose a big challenge to the diminishing available resources, environmental quality and human well-being. Cities in Africa continue to experience a fast horizontal growth of settlements due to influx of people from rural areas who often settle in the economically lowest segments in urban areas. This horizontal rapid growth has eaten up land set for agriculture around cities and promoted the rapid growth of informal settlements exacerbating the impacts of climate change leading to a negative impact on agricultural production. Policies linking rapid urbanization and climate change with agricultural productivity are need. This study explores and documents the impact of rapid urbanization on climate change policies and subsequent impact on agriculture in Africa.

Chapter twenty one analyses climate change mitigation in view of collective efforts and responsibility. Climate change caused due to our careless activities towards our nature, ecosystem, and whole earth system. We are paying and will be paying in future for our irresponsible activities in past and present. Increased concentration of Green House Gases (GHG) has caused severe global warming which will cause melting of glacier and results in sea level rise. To avoid and reduce the intensity and severity of global warming and climate change, its mitigation is essential. In this chapter we have focused on various issues related with climate change and mitigation strategies.

Chapter twenty two studies resources dependent livelihood in Indian Coastal Sunderbans. Millions of people in Sunderbans generate their livelihood and sustenance through fishing, honey collection, fuel wood and timber. The paper attempts to examine the issues of coastal poverty, food security as well as livelihood insecurity and the adaptation options that help to the resilience of climate change. The paper is based on field survey conducted in the villages of Sunderans in 2011. The study revealed that fishing and crab collection, honey collection are the important sources of livelihood. The fishing resources have been declining which leads to the insecurity of livelihoods of the fishing communities. The study has identified the key adaptations like dependency of money lenders, fishing and crab collection, formation of Self Help Groups, livestock rearing and migration. This paper has important policy implications for poverty, livelihood vulnerability and migration.

Chapter twenty three investigates climate change and adaptation in Darjeeling, Eastern Himalaya, through the lens of capability approach. Climate Change has disproportionate impacts on developing countries. Government and development agencies have initiated programs to enhance adaptation of local communities. This study aims to see the benefits of such programs in Darjeeling district of West Bengal. To gauge the benefits to local communities, focus group discussions were held. Findings from fieldwork suggest that most of the intervention made focused on income, resources, and assets in health, education, housing and livelihood sector. These have failed to benefit communities as planned due to variation in capabilities of different sections and lack of conversion factors, like gender equality and transparency. Hence, such project-based approach to enhance community's adaptation fails to show benefits because predefined aims of the project do not lead to expansion of communities' capabilities and real freedom. Further, it is important to understand community as agent of change rather than merely beneficiary. Therefore, to enhance community's adaptation, interventions should aim to enhance the range of choices.

Chapter twenty four discusses what constitutes adaptation responses by firms in the face of climate change. There are four integral components of adaptation activities undertaken by firms: assessment of risk, understanding of vulnerability, understanding the regulatory barriers to overcome the vulnerability, and, finally, adoption of policies to overcome the vulnerability. While it is easy to understand these components separately, their interdependencies make the overall picture is more complicated since. Also complicating the issue is the fact that most small and medium firms do not have the capacity and resources to predict the impact of such changes on their operations, and hence, to quickly make the adjustments necessary to overcome them. The response of firms also depends on the nature of the climate risk they face, whether it is sea-level rise, or temperature rise.

Chapter twenty five highlights the importance of scalable time series analysis. Space and time related data generated is becoming ever more voluminous, noisy and heterogeneous outpacing the research efforts in the domain of climate. Nevertheless, this data portrays recent climate/ weather change patterns.

Thus, insightful approaches are required to overcome the challenges when handling so called "big data" to unravel the recent unprecedented climate change in particular, its variability, frequency and effects on key crops. Contemporary climate-crop models developed at least two decades ago are found to be unsuitable for analysing complex climate/weather data retrospectively. In this context, the chapter looks at the use of scalable time series analysis, namely ARIMA (Autoregressive integrated moving average) models and data mining techniques to extract new knowledge on the climate change effects on Malaysia's oil palm yield at the regional and administrative divisional scales. The results reveal recent trends and patterns in climate change and its effects on oil palm yield impossible otherwise.

Chapter twenty six examines trade performance of climate friendly goods using some trade indices for South Asia and Asia Pacific countries during 2002 - 2008. Climate friendly goods (CFG) are those goods which are less harmful to environment. Paper identifies performance of Asia Pacific region in CFG trade with other nations. Most of the countries in Asia are importers of climate friendly goods and technologies. The Comparative advantage analyses indicate that Hong Kong, China, and Japan have comparative advantage in the production of CFG goods and are net exporters of such products. The competitiveness measures also show that China, Hong Kong and Japan, and Asia Pacific region are major exporter of CFG during 2002-2008. Competitiveness of China and South Korea has improved in 2008. Pakistan, Sri-Lanka, and India prefer to trade in CFG regionally and have shown interest in production and trade of clean coal technologies (CCT). India and Pakistan enjoy comparative advantage in CCT trade. East and South East Asia regions have comparative advantage in Solar Photovoltaic Systems (SPVS) and Energy Efficient Lighting (EEL). China is performing better than other in EEL. Japan, China, Malaysia and Macao show good in 2008 for SPVS. Japan, Philippines, China, Hong Kong and South Korea have a comparative advantage in production of *other climate friendly* items in 2008. This study also identifies the potential trade partners.

Chapter twenty seven critically examines the emission trading scheme and policies. Pursuant to the Thirteenth Conference of Parties to the UNFCCC held at Bali in 2007, based on Nationally Appropriate Mitigation Action plan, India has introduced its very own Emission Trading Scheme (ETS) called Perform, Achieve and Trade (PAT) market mechanism. The country has already achieved remarkable success in the renewable energy front. This chapter studied the existing policy regime of renewable energy and energy efficiency, and tried to understand how far the country practically can achieve the objective enshrined by PAT mechanism. This paper highlighted the background of the market based ETS, where various policies and legislation were put in place to provide energy efficient service and energy efficient system to the large energy intensive sectors of Indian economy. However it is not conducive to come to a conclusion regarding PAT's success or failure unless the First PAT cycle is completed.

Chapter twenty eight examines the influence of fiscal policy on carbon emission in a cross country analysis. They suggest that countries disburse subsidies with various motivations, e.g. to promote industrial development, facilitate innovation, support national champions, ensure redistribution. The devolution of subsidies may, however, also encourage economic activities leading to climate change related concerns, reflected through higher greenhouse gases (GHGs) emissions, if economic activities are conducted beyond sustainable point. Through a cross-country empirical analysis involving 131 countries over 1990-2010, the present study observes that higher proportional devolution of budgetary subsidies lead to higher CO_2 emissions. The countries with higher CO_2 emissions are also characterized by higher per capita GDP, greater share of manufacturing sector in their GDP and higher level of urbanization. The results further demonstrate that structure of the economy is a crucial determinant for per capita CO_2 emission, as countries having higher share in agriculture and services in GDP are characterized by lower per capita CO_2 emission. In addition, the empirical findings underline the importance of the type of government subsidy devolution on CO_2 emissions. It is also observed that countries having high tax-GDP ratio are marked by lower per capita CO_2 emission, implying government budgetary subsidy is detrimental for environment whereas tax is conducive for sustainability. The analysis concludes by noting the importance of limiting provision of subsidies both in developed and developing countries.

Chapter twenty nine attempts to understand the climate change induced social innovation. In his chapter an attempt has been made to link the understanding relating to innovation in organisations with that of societal innovation at large which was later on extended to summarise the literature of social innovation and climate change. The organisation forms part of the social system, which may be seen as consisting of two levels while the immediate vicinity of the organisation encompasses the various organisational stakeholders and correlates the second level pertains to society in general. The second level encompasses the first which in turn encompasses the organisation. A comprehensive review has been presented for a better understanding of social innovation its correlation with climate change through the concepts used to understand organisational innovation.

Chapter thirty provides a content analysis on model of eco-innovation. Complexity of sustainability issue in operations management leads this study to determine a parsimonious model of eco-innovation. Most of research findings have been emphasized on the effect of innovation on company's economic benefits. However, there is inadequate study in respect to eco-innovation and impact to business and environmental sustainability. This is causing a lack of study on this topic. The chapter focuses on determinants of drivers of eco-innovation and seeks the impact to the outcome of sustainable business performance. Content analysis is used in order to explain phenomena of eco-innovation in operations management and categorize the determinants of drivers. The unit of analysis of this study is driver or factor of eco-innovation which commonly uses in entire articles. The scope of review encompassed articles published during 1994 to 2012. Results indicate that a parsimonious model of eco-innovation was consisted of five drivers. More comprehensive and robust findings could be obtained by testing this model and broadening the scope of study.

This handbook will be a good reference book on climate change impact on health and sustainable development for new learners for the coming years. I also expect that these research outcomes will assist the academicians and policy makers all around the world to have a better understanding of the said climate change and environmental sustainability that the book addressed to and making themselves prepared to visualize impact assessment, and identify the mechanism design for implementing possible adaptation and mitigating policies.

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Section 1
Health

Chapter 1
Exacerbating Health Risks in India due to Climate Change:
Rethinking Approach to Health Service Provision

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ABSTRACT

While climate change is expected to exacerbate human health risks, it also provides an excellent opportunity for defining and implementing preventive actions. Developing nations like India, with low infrastructure facilities, limited resources, varied development priorities and, often with large population, are particularly vulnerable to health impacts - more so under the climate change regime. The greatest challenge facing the current Indian health service provisioning system is that it has to cater to the health service needs of its large population within a short time and with sustainable impact. Limited health 'cure infrastructure' (low per capita availability of doctor, hospital beds, etc.), lack of qualified health practitioners, absence of a strong monitoring system in disease surveillance and rising cost of 'cure infrastructure' are some of the major drawbacks of the existing system in India. There is therefore, a need for mainstreaming more preventive measures which will enhance human health resilience and make the population less exposed and more resilient to the predicted impacts of climate change. To provide preventive care to the Indian population, a paradigm shift in strategy is required. The new regime needs to emphasize on an integration of 'traditional preventive health care systems' with modern cure targeted pharmaceuticals and non-health sector interventions. Such a system is expected to reduce the long term demand for cure infrastructure and will provide a more holistic inclusive solution to the Indian problems.

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INTRODUCTION

Human health status determines individual and societal wellbeing. Climate change induced health impacts are expected to put additional stress on human wellbeing and equity through intra-generational and inter-generational health outcomes. Understanding the climate change-human health interaction is imperative for following a pathway of sustainable development. In India, there is paucity of evidence, assessment, research based knowledge and communication on climate change induced health risks, and intervention need assessments. Simultaneously, there is a fair degree of inadequacy in the infrastructure for provisioning healthcare services. In our view the gap will become critical in the face of emerging climate induced health risks in India.

Past research shows that the most important threat to India's sustainable development is poor performance in the health related indicator (Roy, Chatterjee, & Basak, 2008) (Roy, Bhowmick, & Dolui, 2014). Climate change will make it additionally worse due to the lack of preventive approach in the health sector (Roy & Netinder, 2010). In this perspective, we argue that, to ensure sustainable development in India and address the emerging health risks in a cost effective way, and for integration and strengthening of traditional scientific practices, there is a major need for development of a National Preventive Health Care Mission (NPHCM[1]) under the umbrella of NAPCC (National Action Plan on Climate Change). This mission mode can facilitate the sustainable development process in the country through targeted preventive actions that can reduce impacts on health and, to a large extent, reduce the accelerating pressure on the health infrastructure delivering cure-based solutions. The goal of this article is to develop the concept and arguments towards the development of NPHCM based on multi-disciplinary, multi-sectoral and multiple health systems approach. A holistic social welfare based system that combines the best approaches in both traditional preventive and modern cure health systems and is governed by the socio-economic realities, is suggested.

Research Strategy and Rationale

This article is based on primary information gathered through expert consultations and data collected from secondary sources. The expert consultations are, by nature, unstructured and exploratory interviews. Experts with national and international experiences in the healthcare provisioning, healthcare policies, climate sciences, economic development, etc. have been consulted during the research process. Further, experts from both public and private sector, together with those from the bilateral and multilateral financing agencies have been interviewed.

We propose institutionalization of climate change induced disease category-wise multidisciplinary action research groups (ARGs). These ARG scan lead, plan and execute a holistic and preventive health care system. This will address climate change induced health risks in the country. With a goal towards sustainable development, the 2009 NAPCC and the Indian Network for Climate Change Assessment (INCCA) of the Government of India are providing a platform for multiple stakeholders to address climate change related problems in the country. However, there is no separate action plan to target reduction of health impacts in the NAPCC. We propose that given the dearth of strategy and the immediacy of the problem, addressing the issues related to health impacts in mission mode would have the advantage of expediting the action through planned steps and targets while, simultaneously, generating ample scope for large scale mobilization of finance from public and private sources as well as global adaptation fund to enhance resilience.

Climate data shows, unambiguously, a rising trend in the mean surface temperature of the earth. Recent projections under different representative concentration pathways (RCP) scenarios predict that this global warming will continue and further accelerate in the future (IPCC, 2013). According to the IPCC (Intergovernmental Panel on Climate Change), if the global society continues to emit greenhouse gases (GHG) at current rates, the average global temperature could rise by 2.6°C to 4.8°C by 2100 (IPCC, 2013). Research indicates that one of the major fallouts of temperature trend can be heat stress (Samet, 2010), (Kjellstrom, Lemke, & Hyat, 2011), (Mathee, Oba, & Rose, 2010), (Roy, 2010), (Roy, Chakrabarty, Mukhopadhyay, & Kanjilal, 2011). Health risks are also posed by exposures to other extreme events like floods, droughts, cyclones, storm surges etc., whose incidences and frequencies are likely to increase due to climate change. These events result in death, disease, mental trauma and malnutrition through water scarcity, loss of food security, increased transmission of infectious diseases as a result of the influence of climate change on disease vectors, societal and economic disruptions due to migration, etc. (McMichael, Woodruff, & Hales, 2006), (Haines, Kovats, Campbell-Lendrum, & Corvalan, 2006)(see Table 1 and Figure 1).Several epidemiological studies assert that occurrence of floods are often ensued by the outbreak of diarrhoea, cholera, typhoid, epidemics, rodent and vector borne-diseases, death, mental disorders, etc. (Kunii, Nakamura, Abdur, & Wakai, 2002), (Ahern, Sari Kovats, Wilkinson, Few, & Matthies, 2005), (Du, FitzGerald, Clark, & Hou, 2010). Droughts cause malnutrition and affect hygiene as water is used mostly for cooking rather than washing, further malaria outbreaks may also follow as droughts impact the vector breeding grounds (Haines & Patz, 2004).

Given the multidimensionality of the problem, there is a growing commitment – among government and policymakers, to integrate health considerations into efforts to mitigate and adapt to climate change at different national and regional levels. But such efforts are still limited (Rumsey, et al., 2014), (WHO SEARO, 2007). To strengthen our arguments for a more concerted and expansive effort to cope with the health impacts of climate change in a demographically expanding country like India, in section 2, we present select examples of first hand research results on health impacts of climate change -heat stress related direct impact on human workability and impact on water quality in urban India[3]. Such specific examples establish why preventive measures/policies/adaptive strategies can enhance resilience to climate change related health impact, and in no way indicates the boundary of the problem. Given the multiple and interrelated health impacts of climate change and space limitations, the authors have tried to limit the examples to manageable proportions.

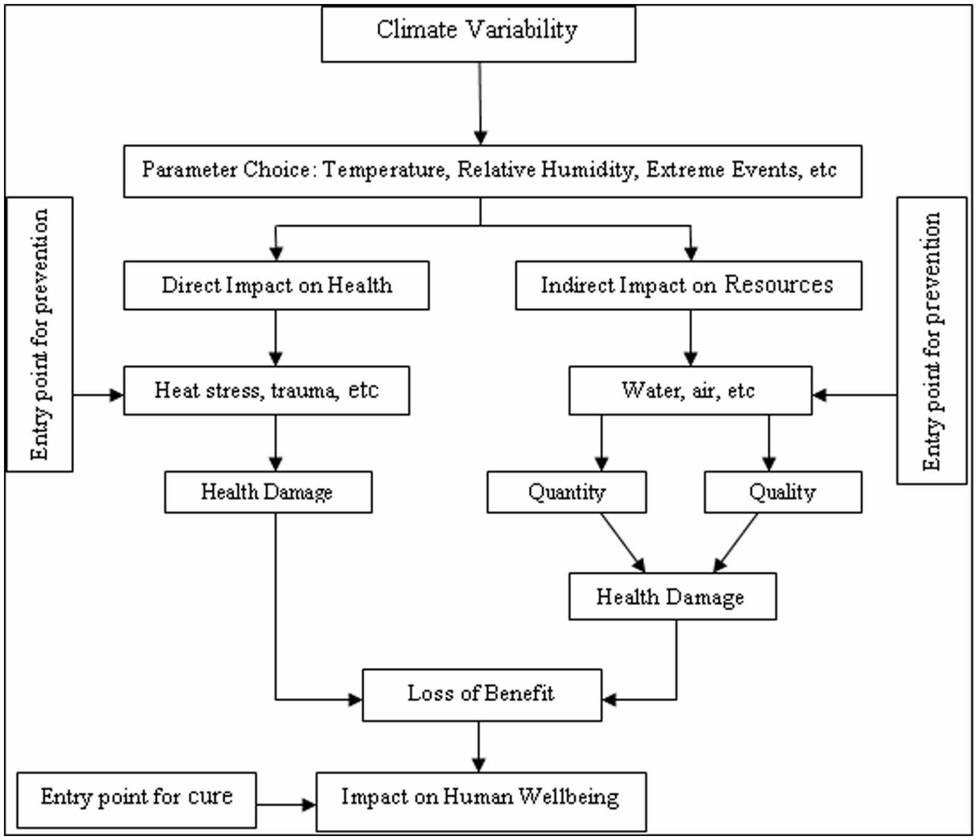
Section 3 presents expert interview based assessment of barriers and gaps in the current

Table 1. Potential health impacts of climate change

Threats	Consequences
Increase in the frequency and intensity of heat waves	Increased mortality from heat waves, especially among the elderly
Change in the distribution of aeroallergens[2]	Increased frequency and severity of allergic diseases and symptoms
Altered distribution of infectious disease vectors	Increased frequency and spread of infectious diseases
Increased air pollution	Increased morbidity and premature mortality
Change in agricultural yields	More undernourished people in low-income countries
Social and economic disruptions due to extreme events, wars, etc.	Water borne diseases, malnutrition

Source: Based on a number of literature review: (Samet, 2010) (McMichael, Woodruff, & Hales, 2006) (Haines, Kovats, Campbell-Lendrum, & Corvalan, 2006)

Figure 1. Health impacts of climate change



cure-focused healthcare regime. The intent is to propose in section 4, an institutional arrangement that might efficiently integrate strategies to combat the climate risks to human health with the extant health care system in the country.

The conceptual framework that has been used to formulate the problem and design a holistic system to manage health impact risks better is guided by an integrated approach (Figure 1) that connects climate variability to human wellbeing loss. We consider preventive care as process intervention and cure as end of pipe intervention. The latter, essentially following the philosophy of "pollute now clean up later approach" is relatively costly as such approach can have many external costs.

CLIMATE CHANGE AND SOME THREATS TO HUMAN HEALTH: INDIAN CONTEXT

India, a major demographic and economic entity among the South Asian nations, covers almost 2.3% of the world's land area while being home to nearly 18% of the world population (NATCOM, 2012). Empirical evidences show that the biggest threat to sustainable development in India comes from relatively worse performance and slow progress in the health sector (Roy, Chatterjee, & Basak, 2008). Analysis of the sustainability indicators in India conducted during 2008-09 show that 28 out of the 35 states and union territories[4] in the country need to prioritize environmental and pollution related health issues in order to be on a sustainable development pathway. The states that need to prioritize environmental issues include Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Punjab, Haryana, Delhi, Rajasthan, Sikkim, Arunachal Pradesh, Bihar, Meghalaya, Tripura, Mizoram, Manipur, Nagaland, Jharkhand, Chhattisgarh, West Bengal, Orissa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh (Roy & Netinder, 2010). Many of these states show that most of their health issues involve vector and water borne diseases together with air pollution related health impacts[5]. Under the projected climate scenarios, the vulnerability to these health risks is likely to increase. Thus addressing the health outcome is a major entry point for integration with climate response strategies[6].

Since the Indian independence in 1947, there has been considerable improvement in the life expectancy of Indians. Life expectancy has more than doubled from 32 years in 1947 to 66 in 2004 (NATCOM, 2012). Mortality and fertility rates have been simultaneously reduced (see Table 4). While these information underscores the benefits accruing from improvements in cure focused medical system, it does not guarantee that vulnerability to climate induced health risks has been or will be adequately managed. Table 2 gives a brief account of the multiple health concerns in India due to climate variability. The magnitude of the problem can be gauged from the fact that India accounts for about 8% of the malarial cases that are reported globally per annum (GOI, 2011). Within the South-east Asian region, 70% of all malarial cases reported annually are accounted for by India. Dengue, identified by WHO as one of the 17 most neglected tropical diseases, is endemic in 31 states and union territories in the country. Of the 350 million global population exposed to the risk of developing kala-azar, about 129 million reside in India. According to the World Health Organization, worldwide, diarrhoea is the second major cause of death among children under five years of age (GOI, 2011). In India 10% of the infants and 14% of the children in the age group 0-4 years die annually due to diarrhoea (UNICEF, 2009). Since the burden of these diseases is expected to proliferate with climate change, therefore, the health risks in India are likely to accelerate if immediate actions are not taken to reduce vulnerability.

Table 2. Climate induced health risks in India

Health Concerns	Vulnerabilities due to Climate Change in India
Temperature related morbidity	Heat and cold related illness Cardio vascular illness
Vector-borne diseases	Changed pattern of disease; malaria, dengue, filaria, kala-azar, Japanese encephalitis and dengue caused by bacteria, virus and other pathogens
Extreme weather events	Diarrhoea, cholera and poisoning caused by biological and chemical contaminants in water Damaged public health infrastructure owing to cyclones, floods, etc Social and mental health stress owing to disaster and displacement
Effects due to insecurity in food production	Malnutrition and hunger especially among children

Source: (NATCOM, 2004)

Vulnerability to climate change impacts is a function of exposure, sensitivity and adaptive capacity (IPCC, 2001). Preventive measures reduce exposure and, hence, vulnerability directly. Depending on the geographic, demographic, socio-cultural, economic characteristics of a place, the vulnerability to climate change varies. In India the vulnerability is high given the diverse geographic features of its large landscape, high population growth rate and an economic system that is predominantly developing[7] in nature. A largely rural society, about 70% of the rural population in India is directly dependent on climate sensitive sectors like agriculture, forestry, and on natural resources such as water, biodiversity, mangroves, coastal zones and grasslands for the continuation of their livelihood (Majra & Gur, 2009). Thus the vulnerability to the adverse impacts of climate change appears high. Natural adversities like heat waves, droughts, floods along with incidences of malaria, malnutrition, diarrhoea, heat related mortality and morbidity, asthma, heart diseases, are some important human health issues that are likely to rise owing to climate change (Majra & Gur, 2009). Our goal is to show - in selected cases how exposure can be reduced by adopting preventive measures.

SPECIFIC EXAMPLES OF HEAT RELATED HEALTH IMPACTS

Heat related illness is often recognized as a major health issue (Kjellstrom, Lemke, & Hyat, 2011) (Dapi, Rocklöv, Nguefack-Tsague, Tetanye, & Kjellstrom, 2010). Given the rising temperature trends and increasing frequency of heat events, health issues like heat exhaustion, heat cramps, heat stroke and death, etc. are on the rise (Luber & McGeehin, 2008), (McMichael, Woodruff, & Hales, 2006). The impacts of heat stress differ depending on factors like adaptive capacity, occupational pattern of the people and hence exposure, age structure, etc. (Table 3).

Table 3. Population most vulnerable to heat stress-Global Indicators

Vulnerable Population	Risk Factor
Elderly (above 50years)	• Poor thermoregulatory mechanism • Impaired cognitive function
Children	• Greater surface area to body mass ratio leading to greater heat gain than adults • Produce more metabolic heat per unit of mass when engaged in physical activity • Less physiologic capacity to sweat • More time to acclimatize than adults
Participants in athletic events	Dehydration
Outdoor workers (street vendors, rickshaw pullers, poor and subsistence farmers and pastoralists)	• Inadequate cooling off or rest periods • Insufficient water consumption • Dehydration • Inappropriate clothing • Excessive sun exposure
Medically compromised and socially isolated	• Mental illness which accompanies social isolation • Inability to avoid heat exposure owing to lack of social contact who can intervene on their behalf

Source: (English, et al., 2007)
(Sahni, 2013), (MMWR Morbidity and Mortality Weekly Report, 2010)

Between 1980 and 1998, as many as 18 events of heat waves[8] were reported in India. The one in 1988 affected about 10 states and resulted in 1300 deaths. Between 1998 and 2000, several heat waves caused an estimated 2120 deaths in Odisha and 198 deaths in West Bengal. In 2003 the heat wave in Andhra Pradesh caused more than 3000 deaths while West Bengal recorded 52 deaths (IPCC, 2007). Between 2001 and 2008, the number of accidental deaths due to heat stroke gradually increased in different states in India, with specific concentration in some particular states like Andhra Pradesh, Orissa, Uttar Pradesh, West Bengal, Bihar and Punjab. The death toll due to heat stress continues to rise (Table A1 in appendix), so much so that in 2010 the percentage share of deaths from heat stroke to total deaths in India was 5.1% (GOI, 2010). Based on data published by India Meteorological Department (India Meteorological Department, 2014), it has been observed that regions with average annual temperature above 25˚C are particularly susceptible to heat waves. Hence states like Andhra Pradesh, Orissa, West Bengal, Uttar Pradesh, Bihar, Jharkhand and Gujarat are highly vulnerable to heat stress.

A case study of Kolkata (Roy, 2010) on the direct impact of heat stress on workability shows that anticipated temperature trend will exacerbate heat stress. During the last forty years in Kolkata, days in April have become warmer by 0.01˚C-0.7˚C per decade whereas days in January have become cooler by 0.04˚C-0.5˚C per decade (Roy, 2010). On the other hand nights in January have become warmer by 0.02˚C-0.9˚C per decade and nights in April have become warmer by 0.02˚C-0.6˚C per

Table 4. Health indicators of India since independence

Health Indicators	1951	Current	Source
Crude Death Rate (per 1000 population)	22.8	7.9 (2012)	(WHO, 2014)
Birth Rate	41.7	22.1 (2010)	(SRS Bulletin, December 2011)
Infant Mortality Rate (both sexes)	146 per 1000 live births	44 (2012)	(WHO, 2014)
Life Expectancy at Birth (both sexes)	32.1	66 (2012)	(WHO, 2014)
Total Fertility Rate (per woman)	6.0	2.5 (2012)	(WHO, 2014)

decade. Such changes are going to be more in the warming direction in the coming decades. Hence, exposure to heat and related health disorders are assuming importance.

The human body functions best within a narrow range of “core” internal temperature that varies from 36˚C to 38˚C. Increase in the core internal temperature leads to heat disorders in human beings. An individual can work safely in an environment for extended periods of time only when the balance between the heat gain due to metabolism and the heat lost to the environment is maintained. Heat related disorders are a group of illnesses caused by prolonged exposure to hot temperatures, restricted fluid intake, or failure of the body’s ability to regulate its temperature. Heat stress has direct implications for human workability through reduced work performance as tired, fatigued workers perform with reduced accuracy, and efficiency (Dash & Kjellstrom, 2011), (Coris, Ramirez, & Van Durme, 2004). (Roy, Chakrabarty, Mukhopadhyay, & Kanjilal, 2011) have used WBGT index (ACGIH, 1995) and measured 100% workability window for Kolkata using 2009 data[9]. The estimates show that for outdoor work categories, e.g. construction workers, traffic police, rickshaw pullers, joggers, walkers, gardeners and cyclists, even in 2009 climate condition and without any adaptation strategy, is failing to provide 100% workdays for more than 9 days in 365 days and even 25% work days are possible for only 44 days without creating any heat stress related health impact (Table A2 in the appendix).

The impacts of heat stress vary depending on adaptive capacity, and occupational pattern of the people (Roy, 2010).The effects of climate change on disease and mortality is expected to have a greater impact on impoverished people who cannot afford minimum living quality (Frakson, 2009). Urban poor are particularly vulnerable to “urban heat island” effect. Excessive heat exposure affects people with certain pre-existing medical conditions like cardio-vascular disease, respiratory illness and obesity.

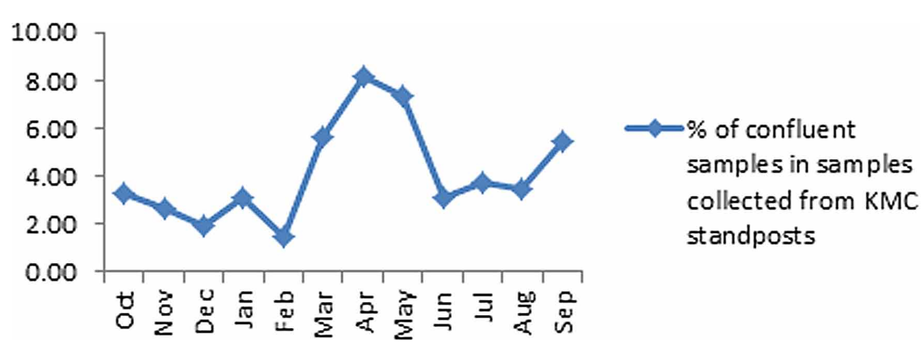
The working population who are exposed to heat for most of the day time are highly susceptible to the heat related morbidity and mortality. Poor and subsistence farmers and pastoralists are not only vulnerable to the heat stress due to their outdoor exposure but also vulnerable to the impact of heat on crop yield and livestock. During the 2003 heat wave in the southern Indian state of Andhra Pradesh, when temperatures rose to almost 49˚C, over 1,200 people died. Majority of the dead were poor daily wage labourers, rickshaw pullers and construction workers (UK Met Office, 2011). Other than the exposure of the working population to heat stress, the elderly population is at higher risk due to reduced ability to acclimatize to changing temperatures and higher likelihood of pre-existing chronic health conditions –the thermoregulatory mechanisms in older adults often do not function optimally, even when the individual is relatively healthy (Nag & Nag, 2009), (Brahmapurkar, et al., 2012), (English, et al., 2007).

Under such circumstances, the conventional, cure-based health care system cannot, possibly, be a solution to combat the emerging risks. A preventive health care system would be more appropriate as that can reduce vulnerability by reducing exposure. Various simulation results show that exposure levels can be reduced by changing clothing type (adaptive capacity), providing shades (exposure reduction), indoor work space (exposure reduction, adaptive capacity enhancement) and air conditioning (adaptive capacity enhancement), and changing work timings (exposure reduction) are possible preventive measures to address heat stress related occupational hazards (Roy, Chakrabarty, Mukhopadhyay, & Kanjilal, 2011) . Costs vary with preventive measures and actions need not always fall under the purview of the health care sector but can lie in formulating innovative labour rules, work hours, dress code, work space design, etc.

A second case study using the Kolkata Municipal Corporation (KMC) data base was also conducted to study the impact of climatic variability on piped water supply to various categories of consumers (Roy, 2010). KMC undertakes regular water sample collection from stand-posts all across the KMC area, outlet points of the booster pumping stations and end-use points in public schools, hospitals and government offices. These are tested for quality in their own laboratory where the physical parameters such as turbidity, taste and odour, colour, chemical parameter such as dissolved chlorine and bacteriological tests are executed. An analysis of the data (Table A3 in the appendix and Figure 2) shows that the percentage of confluent samples (i.e. samples in which coliforms of faecal/non-faecal origin are found) is found to increase significantly in summer and monsoon seasons. Discussion with the KMC scientists revealed that in summer, with rise in temperature, the amount of dissolved chlorine in piped water reduces. This increases the likelihood of bacterial growth in the piped water.

The quality aspect of the piped water supplied by the KMC has long-term sustainability implications in view of climate change. Under the climate change scenario a significant prediction is that summers will be prolonged (Roy, 2010). This may lead to a significant deterioration of water quality for a long period, thereby increasing the consumers' vulnerability to health risks. Preventive health care - by maintaining water quality with additional efforts from KMC, can save both public and private cost of curing water borne diseases like diarrhoea, cholera, hepatitis

Figure 2. Seasonal variations in quality of piped water in KMC area



and typhoid. These examples show that preventive health care measures can happen across sectors to deliver benefits in the health sector.

INTEGRATING "CLIMATE CHANGE" AND "HEALTH ISSUES": GAP IDENTIFICATION

It is important to understand gaps in the existing system to suggest any institutional reform. We present current cure system focused institutional adequacy and an assessment of climate change induced health impact awareness among health sector decision makers.

Brief Overview of the Indian Health System and Policy

The Indian healthcare system has witnessed a sea change since independence in 1947. The transition of the Indian health system has basically been a combination of demographic transition (shift from high mortality and fertility to low mortality and fertility), epidemiological transition (from mal nutrition to communicable diseases of childhood to chronic diseases of adulthood), social transition (from low to high knowledge and expectations about the health services) and technological transition (both diagnostic and therapeutic) that have contributed to shift in policies and programmes with cure focus in the health sector (Peters, Rao, & Fryatt, 2003). The National Health Policy (NHP) formulated in 1983 and then revised in 2002, puts forward the basic goal to improve health, and further deliberates on the methods and policies to achieve the same. The long term goal of the NHP is to achieve, by 2045, a stable population that is consistent with sustainable economic growth, social development and environmental protection. After more than half a century of independence, the performance of the Indian health system has been satisfactory with respect to these goals (Peters, Yazbeck, & Sharma, 2002), yet a lot more needs to be achieved.

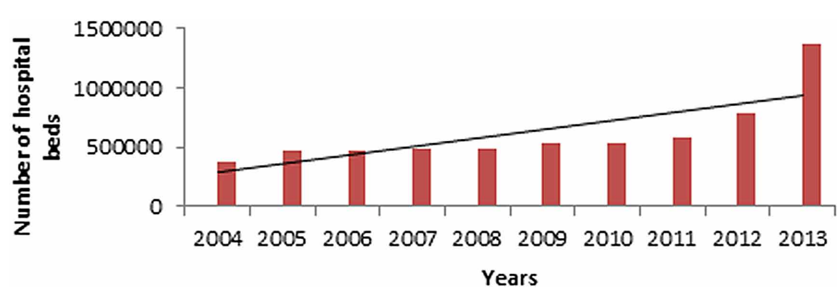
The greatest challenge facing the current Indian health service system is that it has to cater to the health service needs of a large population within a short time with sustainable impact. With 21.92% of the population, living below the poverty line, it is undoubtedly a tough challenge (GOI, 2013). Since independence, the primary goal of the policy makers has been to ensure regional and demographic equity in the distribution of health services in the country. So far, the Indian health policy has accorded importance to visible issues like maternal mortality, maternal health, infant mortality and child health, malnutrition and undernutrition, and reducing the incidence of certain communicable diseases like malaria, dengue and cholera that can lead to the outbreak of epidemics. These have been the main concerns of the policy makers particularly in the poor and less developed regions of the country (Peters, Yazbeck, & Sharma, 2002). However, the significance of the integration of climate change impact control measures and health strategies – an important aspect of sustainability, has been lost (Patil, Somasundaram, & Goyal, 2002). After over fifty years of independence, 40% of the deaths in rural India are due to infectious diseases and 80% of the sickness is due to waterborne diseases (Patil, Somasundaram, & Goyal, 2002). While the immediate problems loom large, preparing for preventive care or planning for the emerging risks due to climate change have been rather peripheral to the health policy of India. To combat the emerging health risks arising due to climate change there seems to be an immediate necessity for a redefinition of priorities and for renewed focus.

A robust cure oriented health system calls for a strong focus on health infrastructure and healthcare personnel. The ratio of doctors to Indian population stands at 1:1800. According to the Medical Council of India, the total number of doctors registered in the country upto 31st March 2012 was 8, 52,195 (Medical Council of India Annual Report (Ammended), 2011-2012). The situation is considerably better in urban India where the doctor-to-population ratio is almost six times than that in the rural areas (Gangolli, Duggal, & Shukla, 2005). Health Statistics shows that India had only 0.7 physicians per 1000 population (OECD average being 3.2) and less than one nurse in 2010 (OECD average being 8.7) per 1000 population in 2011. While the global ratio of hospital beds per 10,000 people is 30, it was only 9 per 10,000 people in India during the period 2005 to 2012 (WHO, 2013). This is despite the fact that during 2004-13, there has been a significant increase in the number of beds in government hospitals (excluding AYUSH hospitals[10] and ESI[11] hospitals). Thus it is evident that the increase in hospital beds has not been commensurate with the population growth rate. Further, an average nursing home and private health facility in India has only 22 beds which is significantly low compared to other nations (Jain & Sandeep, 2009). WHO had estimated that India will need an additional 80,000 hospital beds each year for the next five years to meet the demands of its population (Bhat, 2006). Again the availability of health facilities in India has a distinct urban bias (Gangolli, Duggal, & Shukla, 2005). Since more than 70% of the population live in rural India (Census of India, 2011), this excludes a large chunk of the populace from the benefits of modern medicine in the country. Thus there appears to be immense scope for investment in the healthcare system in the country. It is also necessary to take a relook at the type of investments being made in healthcare in the country so as to ascertain whether climate resilient investment has been an objective of the health policies so far.

Health Infrastructure in India

Over the years the public health investment in India has traditionally been low (GOI, 2002). Health expenditures computed on the basis of a few selected list of National Health Account indicators for the years 2000 and 2011) (Table 6) show that during the last decade there has not been any satisfactory improvement in expenditure on health in the country. The contribution of public funds to total health expenditure has been consistently lower than private expenditure. In most developed economies, the general norm is that health services are largely funded by the government. In India however only about 30% of the total expenditure on health is contributed to by the government, the rest is financed privately. An idea about the public healthcare system can be had from the country's HDI ranking (UNDP, 2014). The HDI is calculated taking into consideration factors like health, education and per capita income. According to the UNDP, out of 187 member countries, India's HDI ranking is 135. A comparative analysis (Table 5) of some major health statistic across countries both developed and developing shows that there is considerable scope

Figure 3. Number of beds in the government hospitals in India (including community health centres)
Source: Compiled from statistics published by the (Ministry of Health and Family Welfare, 2014)



for government action in the healthcare system in India. This scenario has encouraging possibilities for the future of healthcare as there is still immense possibility for the government to intervene with policies that can henceforth mainstream climate responsive health infrastructure into the health care framework of the country.

A further analysis of the recent health policies in the country reveal that improved rural healthcare and access to affordable public health systems have been accorded necessary priority in the country. The National Rural Health Mission: 2005-2012 (NRHM) is a major initiative by the Indian government that seeks to provide effective healthcare to the rural population throughout the country with special focus on 18 states that have weak public health indicators and/or weak infrastructure. The NRHM programme is also aimed at improving public health infrastructure and access at the community level through increased decentralization of health functions (Table 8). Furthermore, the Government of India launched the Rashtriya Swasthya BimaYojana (RSBY) program in April 2008. The initiative is aimed at providing low-cost health insurance coverage to BPL (below poverty line) patients and to those engaged in the unorganized sectors, who might not have previously been insured or been able to afford medical treatment. Under the RSBY scheme, beneficiaries are entitled to health insurance coverage of up to Rs. 30,000 per year. Patients covered under the scheme can avail cashless transactions to gain access to treatment in hospitals and healthcare centres registered under the RSBY scheme. The scheme entails a public-private partnership between the government and private insurance companies. Although the scheme is fairly recent and still operating at a small scale, RSBY has attained some success in states such as Maharashtra, Uttar Pradesh and Bihar.

Recent trends in health policies in India emphasize the need to incorporate climate oriented health systems in the country. Ensuring accessibility to health systems and improving rural health infrastructure ensures the equity goals of the country's national health policy. However, besides distributional and regional equity there is both necessity and possibility for incorporating climate driven systems that while ensuring the immediate equity and accessibility issues; also guarantee the long term/ inter-generational equity and sustainability criteria. In this regard there is already in place a traditional medical system that through restructuring and proper administration might address the sustainability goals of the Indian health system while being both affordable and accessible to all.

Table 5. Hospital beds (per 10,000 population) during 2005-2012

Country	Hospital Beds per 10000 People
Global	30
Japan	137
Australia	39
Norway	33
UK	30
USA	30
Sri Lanka	36
Brazil	23
China	39
Malaysia	18
Pakistan	6
India	9
Bangladesh	6
Niger	…
Ethiopia	63
Nepal	50
Senegal	…

Source: (WHO, 2013)

Table 6. Measured levels of expenditure on health in India

Selected National Health Accounts Indicator	2000	2011
Total expenditure on health as % of GDP	4.3	3.9
General Government expenditure on health as a % of total expenditure on health	26.0	30.5
Private expenditure on health as a % of total expenditure on health	74.0	69.5
General government expenditure on health as a % of total government expenditure	7.4	8.2
External resources for health as a % of total expenditure on health	0.5	1.1

Source: (WHO, 2014)

Table 7. Health indicators (2011) and health spending (2010) in selected countries

Country	HDI Rank 2013	Life Expectancy at Birth (Years)	IMR	Total Health Spending as a % of GDP	Govt. Spending on Health as a % of Total Spending on Health	Private Spending on Health as a % of Total Spending on Health	Govt Spending on Health as a % of Total Govt Spending	External Resources for Health as a % of Total Spending on Health
Norway	1	81	3	9.3	85.5	14.5	17.7	…
Sweden	12	82	2	9.6	81.0	19.0	14.8	…
Japan	17	83	2	9.2	80.3	19.7	18.2	…
USA	5	79	6	17.6	48.2	51.8	19.9	…
UK	14	80	4	9.6	83.2	16.8	15.9	…
Malaysia	62	74	6	4.4	55.5	44.5	9.2	0
Brazil	79	74	14	9.0	47.0	53.0	10.7	0.3
Sri Lanka	73	75	11	3.5	45.6	54.4	6.9	2.2
India	135	65	47	3.7	28.2	71.8	6.8	1.3
Pakistan	146	67	59	1.0	76.6	23.4	3.4	10.2
Niger	187	56	66	4.8	49.2	50.8	11.1	32.7

Source: (WHO, 2013), (UNDP, 2014)

GAPS AND CHALLENGES

Based on the expert interviews (Roy & Netinder, 2010) and supplemented by secondary information the gaps that impede the capacity of the Indian health sector to combat the emerging climate induced health risks have been identified (Tables 9, 10). The gaps mainly emerge due to the absence of proper integration of climate change related stresses in designing approaches and policies for the health sector in India. Table 9 represents a summary of the barriers while table 10 summarizes the gaps.

ALTERNATE HEALTH POLICY REGIME AND SUSTAINABLE DEVELOPMENT IN INDIA

Health is often regarded as capital as it increases human productivity and thus augments income generation capacities and social welfare. It is, therefore, imperative to ensure both public investment in health infrastructure and management, as well as private investment for the maintenance of personal health. In literature, investment in both public and private health is advocated to ensure sustainable development in the long run.

Table 8. Goals and strategies of NRHM (2005 -2012)

Goals	• Universal access to public health services such as women's health, child health, water, sanitation & hygiene, immunization and nutrition • Prevention and control of communicable and non-communicable diseases, including locally endemic diseases • Increased access to integrated comprehensive primary healthcare • Population stabilization, gender and demographic balance and promotion of health lifestyles • Reduction in Infant Mortality Rate (IMR) and Maternal Mortality Ratio (MMR)
Core Strategies	• Train and enhance capacity of Panchayati Raj Institutions (PRIs) to own, control and manage public health services • Promote access to improved healthcare at household level through the female health activist (ASHAs) • Health plan for each village through Village Health Committee of the Panchayat • Strengthening sub-centre through an untied fund to enable local planning and action and more Multi-Purpose Workers (MPWs) • Strengthening existing Primary Health Centres (PHCs) and Community Health Centres (CHCs) and provision of 30-50 bedded CHC per lakh population for improved curative care to a normative standard (Indian Public Health Standards defining personnel, equipment and management standards) • Preparation and implementation of inter-sectoral District Health Plan prepared by the District Health Mission, including drinking water, sanitation hygiene and nutrition. • Integrating vertical Health and Family Welfare programmes at National, State, Block and District levels • Technical support to National, State and District Health Missions for Public Health Management. • Strengthening capacities for data collection, assessment and review for evidence based planning, monitoring and supervision • Formulation of transparent policies for deployment and career development of Human Resources for Health • Developing capacities for preventive healthcare at all levels for promoting healthy life styles, reduction in consumption of tobacco, alcohol etc • Promoting non-profit sector particularly in underserved areas.

Source: (Ministry of Health and Family Welfare, 2005-2012)

In India, for a very long time, an alternative health system that stresses on man-nature interaction– AYUSH, has prevailed. Over centuries, this traditional system had effectively provided health care to a large section of the population. More a preventive medical regime, the popularity of AYUSH can be attributed to its low cost and its "individual" or one-to-one form of treatment (Moreno Leguizamon, 2005). Climate change impacts and adaptation strategies which call for more preventive actions for certain disease types needs to be newly embedded in the existing system. Existing preventive measures focus only on strengthening of immunization programmes. In India, the Primary Health Centres (PHCs) that act as the first contact point between the villagers and the medical officers in the rural areas, were envisaged to provide an integrated curative as well as preventive health care to the rural masses with a strong emphasis on the preventive and promotional aspects of healthcare. As on March 2012, there are about 24,049 PHCs functioning in the country (Ministry of Health and Family Welfare, Government of India, 2012). Their activities mostly involve providing curative, preventive, promotive and family welfare services.

Post 1947, the Indian health policy, encouraged by the western system of modern pharmaceuticals, had focused more on a curative health system. Consequently, with policy and institutional patronage, a curative regime with appropriate supply chain and network penetrated fast to compete away the traditional preventive system. Further, with the advancement of medical science, a number of

Table 9. Barriers in mainstreaming climate change in the Indian health sector

Area	Observations Concerning Climate Change and Health
Integrating climate change and health at the policy level	• Issue of climate change is yet to "seep down" to people who matter – the politicians, policy makers, etc.; impacts of climate change are often considered as "distant". • Awareness about the "phenomenon" called climate change may be existing at the highest level (the government) but there may be absence of "realization" among decision makers about exact impacts at the local level impeding area specific intervention(s). • Although it is important to start planning to tackle the emerging risks from climate change in the health sector, recognition of this requirement, especially, at the policy and the budget level is still awaited. • There may be a view at the policy making level that there is not enough evidence (of how climate change will affect health) to plan for interventions. • So far, there is almost no programmatic approach at the policy level to devise strategies for the health sector with climate change as a perspective. • The issue of climate change is often recognized as an "additional burden" and "an issue with uncertainty in scientific knowledge and understanding." For the present health system of India, already plagued with a number of problems – maternal mortality, infant mortality, malnutrition, etc., it may be too ambitious to plan for an uncertain issue. • NAPCC is yet to consider all the health effects of climate change - only a few diseases like dengue and malaria are addressed under the disaster management strategy of NAPCC. • Governments, both at the centre and states is yet to declare an integrated action plan in the health sector incorporating the emerging health risks due to climate change.
Integrating climate change and health at the operating level	• Decision makers at the operating level are "yet to internalize" the scientific information on climate change and health risks for deciding on the local actions for mitigation and adaptation. • Doctors and health workers delivering health services are not specifically aware of the relation between climate change and the emerging health impacts. • Medical curriculum in the country is yet to factor-in climate change as a determinant of health. • The health delivery system is yet to be prepared to deal with climate change induced health impacts.
"Approach" of the present "health system"	• In India, the health delivery mechanism spends more time in treating the conventional diseases. The approach is primarily "curative" rather than "preventive". Climate change related health impacts need more preventive approach and is a public health issue as the impact is expected to be more on the poorer section of the society. • While a sound public health policy should focus on reduction of preventable diseases, in India, this philosophy has limited evidence in the health related programmes. • The public policies and systems in India are still saddled by the debate on according importance and attention between the burden of classical diseases and the emerging health risks. As on date the planning for emerging health risk is treated as a peripheral activity. • Actions to increase the awareness among communities and strengthen the participation of communities for "preventing" diseases have less-than-required emphasis. • The present approach of curative care is not adequate to increase the preparedness of the system for fighting climate induced health risks.

Source: (Roy & Netinder, 2010)

wonder drugs that effectively treated hitherto incurable diseases flooded the market providing mass scale relief for specific illness. Consequently, the traditional health management systems were marginalised. However, climate change induced health impacts have revived the demand for investment in preventive health care as a possible adaptation policy (Haque, Louis, Phalkey, & Sauerborn, 2014). Research shows that indigenous medical systems provide safe and effective therapies, are readily accessible even in remote rural areas and are more capital and energy efficient than modern pharmaceuticals as the former are based on locally available resources that requires little transport and preservation costs (Carlson, 2000).

To provide preventive care to a large population it is necessary to develop a holistic health care medical system. Paucity of health workforce in

Table 10. Climate change and health in India: gap analysis

Disease Surveillance System	In India the system of gathering consolidated information about incidence of diseases may be less than efficient. A good monitoring and evaluation system is the need of the hour – disease records are to be managed efficiently to generate early warning systems. The information base can be used to identify the emerging health risks
Manpower in the health sector and Psyche of the population	• Adequacy of training/awareness among the health workers at the grass-root for delivery of public health is questionable. The number of trained doctors/nurses working at the government facilities at the grass-root level is far from adequate. • Poor people spend money and end up visiting a quack. • Citizens are oblivious of the fact that health is a right • Illiteracy and poverty leads to faulty health-seeking behavior among the population. Myths and misconception leads to reliance on religious customs for cure. • Poor rural population is often afraid of approaching the organized healthcare facility as they are thwarted by the rude behaviour of the doctors and nurses.
Institutional Capacity within the country	• The issue of the absence of "inter-sector convergence" is an important barrier and there may be less than adequate collaboration among ministries and departments (meteorology, social welfare, rural and urban development, veterinary, water and sanitation, health, environment, etc.) in preparing the health sector in India to combat the climate induced health risks. Ministries are yet to identify their own contributions to design a prepared health system in the perspective of climate change. • Urban India, primarily, is increasingly serviced by the private players in the health sector; there is little confidence in the government infrastructure for health care. • Healthcare is becoming increasingly less affordable to large number of population. • • Health insurance is not supported by the state. Health insurance for the rural poor has just started but the coverage, as yet, is low. • Access to health services – best in the city, poorest in the rural areas. Often, factors like difficult terrain, insurgency, etc. pose a challenge in delivering health facilities • Rural areas in the country face serious constraint in the form of inadequate availability of medicines • Availability of doctor per capita is miserably low; so also is the availability of hospital beds (and other such infrastructure)
Absence of a desired "Bottom-Up" Approach	• Stakeholders, particularly, at the grass-root are, very often, not consulted while devising strategies and policies for the health sector. • The current system may be plagued with a "one size fits all" approach for delivery of health care in India. There are both spatial and temporal variations in the problems. Specific regional problems are to be analyzed and understood and the results to be used by policymakers in addition to involving communities for policy design .Hence, innovation has to be inbuilt in the policy design. • Health care system is yet to recognize that morbidity and mortality have to be managed through the interplay of multiple disciplines.
Absence of region specific information and evidence	• There are many districts in India which are experiencing temperature and precipitation change for the past few years. What have been the effects (of such change) on the vector borne diseases? Is there a chronic heat effect? Is there an evidence of child mortality/ neo natal mortality with temperature rise? Are there evidences of the emergence of new viruses due to temperature rise? Evidences and case studies are missing. • One cannot say how the public health system should respond to the emerging health risks if one does not know with more confidence on exact cause-effect relationship between climate change and health with a region-specific focus. • Prospective studies on the health effects of climate change are yet to be commissioned. Answers to some of the following questions are still awaited: o What will be the health impacts of extreme heat /flood in the future (say, 2030/2050/2080)? o What will be the vulnerability profile of the districts and regions as a consequence of different scenarios of climate change? o What could be the adaptation strategies? What technological solutions are possible? • Research needs to be directed at finding out "local" evidence(s) and possible impacts. It is only then policy makers can be convinced and proper planning will be possible. • Also there is need for evidence based policy briefs for different levels of government(s) for initiating action for mitigating health effects of climate change and scaling up adaptation capabilities. • As on date, there exists gap in communication between scientific research and communities at the grass-root. This gap needs to be bridged. Findings from scientific research (relation between climate change and health) are to be communicated to the communities in the language they understand.
Political will	Politicians gain from planning for the immediate problems showing immediate results in economic gain. More attention, therefore, is directed towards the conventional problems rather than new emerging issues with uncertain outcome
"Prevention" and "Climate Change" – not top of the mind recall among the population	A large proportion of the population does not recognize the preventive measures. Further, common people are yet to recognize and realize the threat to health posed by climate change.

rural India along with lack of interest in modern allopathic graduates to serve the rural poor has worsened the situation in India (Samal, 2013). The challenge therefore is to revive the traditional medical systems, make them less individual oriented and integrate them with the public health system. To do this, it is necessary to understand the science behind such systems as this will help mainstream the traditional systems in the policies designed for preventive care. A holistic preventive health care system may come into existence through a successful co-existence of two regimes -the traditional health care systems and modern pharmaceuticals. The concept of mainstreaming AYUSH was an idea in the IXth five year plan before it was actually implemented in the country by NRHM in 2005. The NRHM put forward an innovative concept of mainstreaming AYUSH doctors at various rural health facilities such as community health centres and primary health centres (Samal, 2013). The rationale behind mainstreaming AYUSH was to strengthen the public health system in the country at all levels by engaging practitioners of alternate medicine. These practitioners have a good presence especially in the rural communities as well as good acceptability from a cultural perspective in the rural areas (Gopichandran & Kumar, 2012). In their paper, Gopichandran and Kumar have put forward a few important challenges in mainstreaming of AYUSH in the existing healthcare system:

1. **Cross Referral of Patients:** There are examples were AYUSH provides a better treatment to an ailment as compared to allopathy. The importance of cross referral, discussions between Ayurvedic and allopathic doctors and arrival at a common point is important in mainstreaming AYUSH in the existing healthcare system.
2. **Prohibition of Cross Practice:** Although legally cross practice has been prohibited by the Supreme Court of India, in many states like Uttar Pradesh, Chhattisgarh, Bihar many AYUSH practitioners are practising allopathic medicine. Since there is a legal restriction on cross practice in India, its implications on mainstreaming have to be assessed.
3. **Distinct Philosophical Orientation of Two Systems:** The philosophical orientation of the two systems viz. AYUSH and allopathy are distinct. While the basis of treatment in allopathy is identification of symptoms and causes of illness based on biomedical model, ayurvedic approach to treatment of illness is completely holistic and places health in the larger context of social, economic, environmental, and psychological situations. The diversity in approaches of the two should very well be kept in mind while integrating the two systems viz. allopathy and ayurveda into the present healthcare system.

In India, the delivery of public health rests on the health workers working at the community level - the Auxiliary Nurses & Midwives, ASHA[12] workers, etc. Most health workers in India are not much aware of the impacts of climate change on health and are hence not skilled enough to prepare communities under their care to cope with such impacts and reduce their vulnerability. Preparing a plan for imparting training to health workers on climate change, its health impacts and possible coping strategies is, therefore, necessary. Furthermore, community participation in developing adaptation plans and capacity building are key components in building climate resilience in rural and economically backward areas that are highly vulnerable to the impacts of climate change. Capacity building through knowledge dissemination and training at the community level is essential to achieve a prepared and responsive health system with an inbuilt principle of preventive care.

In India the apparent dichotomy between "climate change" and "health" (at the policy level) exists because there are serious research gaps regarding the exact relation between climate change and possible health impacts and the care needs. Focused research in building up case studies at the local level, experiments for exploring efficient and effective coping strategies and adaptive capacities are required to initiate actions at the policy level. Not only historical studies but also prospective studies are required to map disease data and climate data for predicting the likely scenario in the future. This is because response cannot be formulated without taking into account evidence. Also, such research is required to develop an "early warning system" in order to increase the preparedness of all the stakeholders exposed to the risk of climate change induced health risks. Some recent experiences of extreme weather events have brought into focus the lack of preparedness – physical infrastructure such as water and health testing facilities for water borne diseases, testing centres to detect new types of diseases, trained medical staff, preventive medicine advisory dissemination institutions, etc. Healthcare technology development for rapid detection, diagnosis and prediction is still at a nascent stage in the country. This enhances vulnerability.

The role of the health administration in health infrastructure management need to be professionally developed and strengthened in India in order to achieve a comprehensive preventive health service delivery system. The current regime advocates a skewed healthcare system that lacks managerial efficiency. New diseases, mutation of pathogens and allergens, changing disease patterns, increase in the spatial spread of disease incidence due to the increase in the frequency and intensity of extreme events, etc. has made it crucial that the managerial aspect of generating quality health services be recognized as a dedicated action plan. This will mean revisiting existing public health laws such as the District and Village Health Plans of the National Rural Health Mission (NRHM) program and charting effective pathways to enforce these regulations. Further, the capacity to provide a holistic health system that incorporates traditional and modern practices need to be incorporated into the agenda of the institutions that provide health care in India.

Health is not an isolated issue but is intensely linked with the drinking water quality, sanitation and air quality both indoor and outdoor. Managing water for drinking purpose and air quality both at public provisioning level and household level needs special attention. There is also need for technology development and deployment, and monitoring of health infrastructure and health indicators for human wellbeing.

Accordingly, a set of action programmes have been considered in envisaging a road map for initiating actions by the Government of India to integrate health and climate change. The aim of the roadmap is to promote sustainable effort to combat vulnerability of the health sector in the face of climate induced health risks. The focused approach, as suggested in the roadmap is not only aimed at improving the existing public health system but to also generate adequate adaptive capacity to cope with climate change induced health risks. The suggested approach incorporates "preventive" measures as an integral component and is called National Preventive Health Care Programme (NPHCP). The NPHCP, through training, advocacy and mainstreaming the preventive healthcare into the existing system aims at reducing the burden of climate induced health risks at a relatively low cost. Bringing into forefront the traditional healthcare approaches like AYUSH is the core strategy of the NPHCP. The programme is envisaged to work in tandem with the existing cure based infrastructure and with various stakeholders – both public and private, and the civil society. The goal is preventive care and not curative treatment. The NPHCP is expected to generate a set of knowledge that may be used to formulate an "approach programme" for building a nation-wide National Preventive Health Care System (NPHCS) or National Preventive Health Care Mission (NPHCM). The goal of NPHCP is to mainstream NHPCS as a planned activity both at the national and the state levels. NPHCP is a research-driven, goal-oriented and strategic programme that is envisaged to have three pillars – knowledge generation, infrastructure planning, and training. The main activities under each of these pillars are presented in Table 11.

Management of the human capital, of which health is an integral part, has very large externalities besides private benefits. Given the public good component of health the government's role cannot be negated. To augment the Indian health system with the principles of preventive care in the light of climate change induced health impacts it is required that multiple agencies work in close tandem. A close cooperation between the ministries will play a crucial role in implementing the programme and mainstreaming it in the national policy.

Given the vastness and variability of a country like India, there is expected to be variability in the effects of climate change on health across population groups and geographical areas. Hence, it is important to formulate "local" studies to develop appropriate and efficient response functions. The control groups may be decided upon based on the known vulnerability of the regions and/or social groups.

CONCLUSION

There is consensus in climate science literature that climate change will have exacerbated impact on human health. It provides a scope to enhance preventive actions to combat and minimize the anticipated adverse impacts on health through exposure reduction. Developing nations like India, with low infrastructure facilities, limited resources, diverse priorities and often with large population are particularly vulnerable to the likely health impacts of climate change. Public

Table 11. Suggested activities in NPHCP

Knowledge Generation	Infrastructure Planning	Training
• Formation of a nation-wide network of institutions and individuals focusing on research related to the issues in "climate change and health" in working groups mode • Linking this network to the international knowledge and experience by bringing together mutually complementary research / training /technology /knowledge sharing institutes and pool of human capital • Developing a collaborative research capacity for modelling the local incidence of disease for designing early warning systems • Building institutional collaboration for exchange programmes for students, researchers, professionals/ bureaucrats, policy makers	• Facilitate preventive health care through devising a programme for information management – a data bank capturing climate parameters, health outcomes/ stresses, hospital data and provide access to researchers to this databank for analysis, decision tool development to help policy making on a continuous basis • Preparing a plan and mechanism for cross country technology diffusion with an aim to promote preventive care • Establishing a collaborative mechanism for development and deployment of technology for preventive cure • Preparing risk management strategy(ies) in the domain of public health in the developing country context keeping in view the size, spread and density of the population • Creating institutional capacity for infrastructure including access to relevant data sets, computing and communication facilities • Designing a plan to complement efforts under the various national missions (in the health and other sectors) through global cooperation (for sharing experiences in different countries)	• Facilitate an improved understanding and awareness of the key drivers of health risks under climate change, especially among the existing and future pool of workers delivering health services in the country • Fostering professional attitude and incorporating preventive care in the health system • Building awareness to improve quality of data - hospital data, disease data, etc. i.e. all kinds of epidemiological data

Source: (Roy & Netinder, 2010)

health care strategy for adaptation can be geared towards mainstreaming preventive, traditional, indigenous health care methods as complementary to the current cure based systems. This approach, if formalized, will include the already existing complementary system which function informally. It is particularly necessary in countries like India that has a much stratified income-educational and social categorization and is currently not covered by modern cure system but is served by informal traditional systems. In this scenario, if the diverse socio-economic structure is neglected while framing future health policies, it will be difficult to impart an integrated and holistic health care to all social strata. The objective is to create and integrate health mission that is target driven, policy oriented and action driven. The traditional Indian health system is largely based on providing preventive health care. Further, it is relatively cheap and individual based. Integration of these two different health care paradigms- traditional and modern, can provide the right kind of inclusive approach to addressing health issues in a developing country under the existing climate change scenario. Once such a holistic system is designed based on the bottom up approach, it will find universal acceptance among all socio-economic classes across nations thus ensuring the future success and robustness of the health system.

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ENDNOTES

1 The idea was presented for consideration in a report submitted to SIDA (Roy & Netinder, 2010). The report was prepared based on an extensive literature review and detailed interview of national and international agencies and stakeholders.

2 An aeroallergen is any air borne substance which triggers an allergic reaction. Aeroallergens include pollen grains, spores etc. Aeroallergens pose a direct threat to many people who already suffer from respiratory illness and people who develop problems after exposure.

3 While, there are numerous ways through which, climate change is expected to have impacts of human health in India, because

of the paucity of space and goal we are not being able to provide a literature review of health impacts. We have restricted our attention to issues concerning heat stress and water quality as specific example to drive the message of need for preventive care through this paper.

[4] In 2008-09, India had 28 states and 7 union territories. However, with effect from June, 2014, the country has been reorganized and the state of Andhra Pradesh has been divided into two sates – Andhra Pradesh and Telangana. Therefore, at present the country has 29 states and 7 union territories.

[5] The distribution of issues is shown in detail in (Roy & Netinder, 2010).

[6] As mentioned earlier, only some threats are being considered so as to keep the focus firmly on possible adaptation measures rather than digressing into long discussion on the interrelated and numerous health impacts from different types of climate variabilities.

[7] Characteristic features of a developing economy includes low income levels, distributional inequality, poor health, inadequate education, low productivity, high population growth and dependency burden, substantial dependence on primary sectors, imperfect markets and limited information (Todaro & Smith, 2007).

[8] According to India Meteorological Department (IMD), a heat wave occurs when maximum temperature of a station reaches at least 40˚C for the plains, and at least 30˚C for the hilly regions. When normal temperature of a station is less than or equal to 40˚C, heat wave departure from normal is 5˚C-6˚C and severe heat wave departure from normal is 7˚C or more. When normal temperature of a station is more than 40˚C, heat wave departure from normal is 4˚C -5˚C and severe heat wave departure from normal is 6˚C or more. When actual maximum temperature remains 45˚C or more, irrespective of normal maximum temperature, a heat wave is declared by IMD

[9] This can be done for any year. Our detailed research does have such information.

[10] Hospitals specializing in alternative medicines -Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homoeopathy (AYUSH)

[11] ESI – Employees' State Insurance Corporation's Hospitals

[12] ASHA: Accredited Social Health Activists are trained female health workers who act as an interface between the community and the public health system.

APPENDIX

Table 11. Accidental deaths due to heat stress in India 1998-2010

States/UTs	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Andhra Pradesh	78	51	56	46	80	100	52	105	125	128	124	262	197
Arunachal Pradesh	0	1	0	0	0	1	0	0	1	4	5	5	1
Assam	4	8	5	7	2	4	16	13	7	7	8	0	1
Bihar	94	94	19	47	22	70	32	68	52	58	28	46	95
Chhattisgarh	-	-	-	5	20	22	9	14	4	15	7	6	10
Delhi (UT)	128	26	34	28	45	18	20	19	14	26	7	40	41
Goa	0	0	0	6	0	0	0	0	0	0	0	0	0
Gujarat	51	38	19	24	47	30	12	13	7	16	6	9	58
Haryana	11	11	7	1	17	2	4	19	13	75	31	34	60
Himachal Pradesh	0	0	1	2	0	8	0	3	1	0	0	1	0
Jammu & Kashmir	0	0	0	0	0	3	2	2	2	1	0	0	6
Jharkhand	-	-	-	2	6	8	19	60	37	38	48	50	49
Karnataka	5	4	5	2	4	6	7	15	5	1	2	9	15
Kerala	7	20	1	0	0	4	1	0	0	1	0	1	2
Madhya Pradesh	109	41	36	8	32	39	158	24	45	41	11	20	46
Maharashtra	66	33	12	43	50	77	62	69	33	70	30	79	137
Manipur	0	0	0	0	0	0	0	0	0	0	0	0	0
Meghalaya	0	0	0	0	0	0	1	0	0	0	0	0	0
Mizoram	0	0	0	0	0	0	0	0	0	1	0	0	0
Nagaland	0	0	0	0	0	1	0	0	0	0	0	0	0
Orissa	112	48	74	60	77	98	76	94	51	55	69	101	130
Punjab	55	28	52	55	39	38	43	87	69	129	64	150	170
Rajasthan	58	25	22	19	57	44	37	38	35	56	29	55	54
Sikkim	0	1	0	0	0	0	0	0	0	0	0	0	0
Tamil Nadu	14	27	25	27	26	54	14	5	23	14	15	31	18
Tripura	2	6	6	4	0	2	0	15	5	0	9	10	12
Uttar Pradesh	137	88	115	52	134	126	95	199	87	108	80	117	118
Uttaranchal	-	-	-	0	0	0	0	2	1	2	0	0	0
West Bengal	85	68	45	66	62	52	96	211	137	86	43	45	54
States	1016	628	534	504	720	807	756	1075	754	932	616	1071	1274

Source: (GOI, 2010)

Table 12. Number of productive days in Kolkata without adaptation in the year 2009

Month (Number of Days)	Number of Days with Productive Time				
	100%	75%	50%	25%	No Work
January(31)	2	6	7	11	5
February(28)	0	2	3	12	11
March (31)	0	0	0	3	28
April(30)	0	0	0	0	30
May(31)	0	0	0	0	31
June(30)	0	0	0	0	30
July(31)	0	0	0	0	31
August(31)	0	0	0	0	31
September(30)	0	0	0	0	30
October(31)	0	0	0	0	31
November(30)	0	3	5	3	19
December(31)	7	3	3	15	3
Total: 365	9	14	18	44	280

Source: Measure of heat stress and loss of productivity – case study of Kolkata, (Roy, 2010)

Table 13. Seasonal variation in piped water quality in KMC area (January – November 2007)

Season	Month	No. of Total Samples Collected	No. of Confluent Samples	% of Confluent Samples In Total
Winter (Oct-March)	Oct	836	29	3.32
	Nov	840	30	2.65
	Dec	623	17	1.93
	Jan	508	16	3.1
	Feb	657	10	1.46
	Mar	890	50	5.66
Summer (Apr-June)	Apr	636	73	8.12
	May	662	87	7.35
	Jun	708	35	3.12
Monsoon (July-Sep)	July	621	52	3.7
	Aug	632	56	3.48
	Sep	776	55	5.41

Source: Socio-economic survey in (Roy, 2010)

Note: Table shows the seasonal variations in water quality at the end-use point at public stand- posts across 128 wards of the KMC area

Chapter 2
Climate Change, Human Health and Some Economic Issues

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ABSTRACT

This chapter attempts to correlate different economic issues like inequality, poverty, green infrastructure and international trade with human health in the context of climate change. In this short survey not only we have tried to capture most of the relevant articles in the corresponding category, but also we have shouted for some of the major research gaps in the form of future research agenda. Interestingly from our short survey we have found that importance of developing as well as less developed economies have been neglected in the context of climate change.

INTRODUCTION

For the last few decades issues on climate change have been gaining more importance among scientists, politicians and obviously among economists. Moreover, since the first attempt at scientific consensus on climate change nearly four decades ago, scientists have been examined whether climate is indeed changing as a result of human activity. Interestingly, economists over the last few decades have also studied the unfolded relationship between the weather, climate, social factors and human health. However, the complicated relationships between climate change, the environment, socio-economic factors and human health have not gained high priorities for scientific research in most of the developed as well as in developing economies, and hence there exists abundant lacunas in our understanding of these relationships. Such gaps impair our ability to identify optimal strategies for mitigation and adaptation that will prevent illness and death in current human populations while simultaneously protecting the environment and health of future generations. The present environmental distorted economic activities of different developing and developed economies have put themselves in such a situation that climate change is currently affecting public health through myriad environmental consequences such as sea-level rise, changes in

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precipitation resulting in flooding and drought, heat waves, changes in intensity of hurricanes and storms, degraded air quality and many more of them. It is to be noted that by the inclusion of just four diseases such as cardiovascular disease, malnutrition, diarrhea, and malaria and floods, the World Health Organization (WHO) estimated 166,000 deaths and about 5.5 million disability-adjusted life years (DALYs, a measure of overall disease burden) were attributable to climate change in 2000. To date, the majority of analyses on climate change and health have focused on diseases that predominantly affect people in the developing world, and therefore, are perceived as less relevant to more developed countries. However, Campbell-lendrum (2007) has explained that as the recent pandemic of H_1N_1 virus has shown us, diseases do not respect international boundaries.

We also have identified several issues that are critical to this discussion including susceptible, vulnerable, and displaced populations with several economic activities; public health and health care infrastructure; capacities and skills needed; and communication and education to increase awareness of climate change health effects. In the case of diseases linked to climate change, a number of populations are particularly at risk. Children, pregnant women, and the elderly are generally more susceptible, especially for heat- and weather-related illness and death, vectorborne and zoonotic diseases, and waterborne and food borne illnesses. Also, children and some minority groups are very susceptible to asthma and allergies that may be exacerbated by climate change. Genetic links and markers that help to identify and define susceptible populations exist for many climate-related diseases. Apart from these here we have also considered the issue of climate change and human health in an open economy.

It is quite clear from the above two paragraphs that analysis related to climate change and human health should provide more emphasis than what is actually prevailing in most of the economies. The main motivation behind this short survey is that though their exist a large number of works have been done on the basis of climate change and human health, but none of these paper have integrated the issues like human health, economic activities, environment friendly infrastructure and international trade in the context of climate change within a single article. In this respect this is the first attempt has been taken to fill up the lacuna of the existing literature. Moreover, in this chapter we have explained the role of several policies associated with adaptation and mitigation from different harmful effects of climate change in a society. Apart from all of these, this chapter have also encouraged the future researchers of this area not only to accumulate various information from different sections and subsections of this chapter but also they can gather their future research ideas from the section of future research agendas. This is also new in the context of existing literature on climate change and human health.

We have mapped our paper in the following manner: In the first section we have correlated the issues like climate change, human health and human activities. By the inclusion of human activities we want to show on one hand that how climate change affects human activities through human health and on the other hand we examine the impact of climate change on human health through economic activities. Impact of environment friendly infrastructure on human health in the presence of climate change has been taken care in the second section. In section three we have integrated the issues such as international trade, human health and climate change. Adaptation and mitigation of several policies regarding climate change have considered in section four. Finally and lastly, we have identified the major research gaps in the form of future research agenda in the last section.

ECONOMIC ACTIVITIES, HUMAN HEALTH AND CLIMATE CHANGE

In this section we are going to analyse the impact of climate change on human health with special emphasis on different economic activities. It is rational to assume that adverse effects of climate change should affect certain economic activities such as agricultural activities, aquaculture activities, etc, through different channels. Interestingly, a large proportion of human beings are either involved directly or indirectly with above mentioned economic activities. Broadly we can speak that here we want to examine the fact that there exist a two way causal relationship between human health and climate change. Firstly, there exist a direct effect of climate change on human health, that is, due to climate change several diseases will degrade human health and incidentally human will work less with lack of efficiency. Secondly, climate change can make a harm to human activities and hence workers will suffer from lack of purchasing power, which in turn make themselves to afford less of health care services.

How does Climate Change Affect Human Health in the Context of Different Economic Activities?

Karl (2009) has claimed that climate change directly affects five components of the environment: water, air, weather, oceans, and ecosystems. People attached with agricultural, aquacultural, irrigation and livestock related activities are massively depends on above mentioned components of environment and in turn severely affected due to climate change. These individuals are not only affected financially but also lose their physical and psychological health status. Financial lose may leads to these victims to a trajectory of poor. Again, poverty, lack of purchasing power, huge unemployment and existence of informal sector generally makes people more vulnerable to many of the health effects of climate change, largely due to inadequate access to health care. Existence of poverty, lack of purchasing power, huge unemployment and existence of informal sector also increases the risk that a population displaced by extreme weather events or environmental degradation will not easily recover, and as a result, will suffer much higher disease risks. Crop and livestock yields are generally sensitive to climatic conditions. Indeed, there is recent evidence that yields can be impaired by quite small changes in growing-season temperatures. Rising temperatures affect rice production, and experimental studies indicate that a $1^{o}c$ rise in average night-time temperature during the later stages of rice-plant growth reduces yields by around one-tenth. Between 1980 and 2008, gains in crop yields related to factors such as technological advances seem to have been substantially offset by the impacts of rising temperatures in many of the world's cropping regions. Rice yields in India, for example, peaked a decade ago, and South Asia's 'green revolution' is now over. Such negative impacts may spread beyond South Asia to include parts of sub-Saharan Africa (some regions of which are particularly vulnerable), southern Europe, the US Midwest and southern Australia. While much public and policy attention has been paid to how climate change might affect food export earnings and rural livelihoods, the ultimate manifestation of reduced food yields is impaired health – hunger, under-nutrition, stunted growth in children, susceptibility to infection, impaired adult health and premature death. Further, in a world of great disparities in wealth, climate-related falls in crop yields can have potentially disastrous effects for the poor via surging food prices. In 2011 the UN Food and Agriculture Organization food price index matched its earlier peak in 2008. This price spike is likely to have been partly caused by the disastrous impact of the mid-2010 heat and fires on the Russian wheat crop, and that price spike, in turn, is thought to have contributed to the social unrest that erupted in 2010 and 2011 in the Middle East and elsewhere. It is unlikely that climate change will cause novel health disorders. Rather, it acts mostly by amplifying existing risks to health. For example, the ongoing rapid urbanization in most low- and middle-income countries is expanding the numbers exposed to the extra local heat caused by the 'urban heat island' effect and global warming will amplify that heat instinct. From the above text it has been cleared that people involved with agricultural, aquacultural, irrigation and livestock related activities are immensely affected by climate change and hence they will suffer from lack of business, which in turn may cause low purchasing power, high unemployment etc,. High unemployment, lack of purchasing power, poverty can affect adversely the affordability of good quality health care. Again, climate change as itself causes harm directly to the human health. Hence, it becomes essential to take a close look on the ways through which human health will be affected due to climate change with special emphasis on several economic activities.

How does Climate Change Affects Aqua-Cultural and Fisheries Related Activities through an Adverse Effect on Water?

Changes in rainfall, changing temperatures, and melting of summer ice caps are already happening and will create changes in the quantity and quality of water across most of part of our earth over the next 30 years[1]. Global climate change is visibly and profoundly affecting oceans, which in turn, affects human health. The warming of ocean waters contributes to increases in incidence and severity of toxic algal blooms, alterations in aquatic and estuarine food webs and seafood quality and availability, and effects on sentinel aquatic species[2].

How does Climate Change Affects Agricultural and Livestock Related Activities Due to an Increase in Heat?

Climate changes including increased heat in certain arid and semi-arid parts of the United States can dramatically alter existing ecosystems, presenting new challenges to agricultural production and coastal ecosystems, with consequences for food quality and availability. In this respect Ericksen (2009) has shown that changes in plant habitat can result in reduced availability of grazing lands for livestock.

So far we have explained the ways through which climate change can affect different economic activities of human beings. Therefore, it becomes crucial to examine the impact of climate change on human health through changes in different environmental factor[3] (these are the same factors that affects human activities).

What are the Ways through Which Human Health can be Affected Due to Climate Change?

Climate changes also are directly associated with many pest habitats and disease vectors, and changes in temperature can extend or reorient habitats such that organisms are introduced to new geographic areas or life cycles are altered, requiring increases in pesticide use or use in new areas to achieve the same yields. Specially, Estrada-Peña (2002) illustrate that Global warming is also causing shifts in the ranges of disease vectors that require specific environments to thrive (for example, Lyme disease) and increasing the threat and incidence in humans of waterborne, vectorborne and zoonotic (those transferred from animals to humans) diseases.

Again, Steenland (2009), Kozma and am J med Genet (2005) and Handal (2007) have told us about the factors affected by climate with particular implications for neurological functioning include malnutrition, exposure to hazardous chemicals, biotoxins, and metals in air, food, and water and changes in pest management. Understanding the role of climate in the incidence and progression of neurological conditions and how to prevent them is a critical need for public health and health care in the United States. Studies such as the National Children's Study by Landrigan (2006) have opened a fine opportunity to improve our understanding in this area.

According to Kozma (2005), Kotermanski (2009) and Miller (2008) exposure to heavy metals is known to exacerbate neurological deficits and learning disabilities in children, and is suspected of being associated with both onset and exacerbation of AD and PD. Evidence suggests that early-life occurrence of inflammation in the brain, as a consequence of either brain injury or exposure to infectious agents, also may play a role in the pathogenesis of PD. In addition to conditions such as PD and AD, Naeem (2005) has shown that post-traumatic stress disorder (PTSD) is likely to have profound effects on the neurological functioning of populations exposed to the stress of extreme weather events, and the resulting dislocation and deprivation that may result from climate change.

INFRASTRUCTURE, HUMAN HEALTH AND CLIMATE CHANGE

It is to be noted that for the past few decades infrastructure has earned immense importance among the economists or policy makers along with different economic activities. After the emergence of Keynesian theories effective demand gets its own role in an economy. Since then it becomes one of the major research area in the field of economic science. Note, better infrastructure or expenditure for better infrastructure can reduced the gap between effective demand and supply of all of the economies. However, in this section we will not consider the efficacy of infrastructure in the way of economic optimization, rather here we are going to analyse the relevance of better or environment friendly infrastructure on human health in the presence of climate change.

Can Better or Environment Friendly Infrastructure Improve Human Health from the Adverse Effect of Climate Change?

Korpela and Hartig (1996) and Korpela (2001) have claimed that regularly visiting a favourite place of natural beauty can be a source of emotional release, enabling people to relax and clear their mind of troubles. Other studies like Kuo (2001), Kuo and Sullivan (2001) and Kim and Kaplan (2004) have found that green spaces visible from apartment blocks reduce residents' mental fatigue. Natural features and open spaces also play an important role in social cohesion at the community level. For example, by encouraging pedestrianism, GI has been found to increase the likelihood of informal interactions and help promote a sense of community spirit. Places of natural beauty can also have cultural and aesthetic value which, in turn, can improve a sense of wellbeing and health.

Tzoulas (2007) has illustrated that environment friendly infrastructure improves the aesthetic look of an area, which in turn effects property prices and attracts tourism and investment to the area, with positive consequences for many socio-economic aspects of a neighbourhood or city, such as employment, income, living and working conditions, access to public services and good-quality housing. This makes a strong case for the contribution of GI to any new development and for the regeneration of urban areas. It has also been acknowledged by Butler and Oluoch-Kosura (2006) that a healthy and well-functioning community is likely to continue to enhance ecosystem services to capitalise on the resources available to them, therefore initiating a positive feedback loop reinforcing the benefits of GI.

United Nations (2001) has been promoting Green Infrastructure (GI hereafter), it is particularly important in urban environments since more than 50% of the world's population live in cities and it is estimated by Hladnik and Pirnat (2011) that most do not have easy access to green spaces. In addition, many other health benefits can be derived from the existence of GI features. These benefits encompass physical, psychological/emotional and socio-economic benefits and can be identified at both the individual and community level.

Several factors related to public health are closely associated with maintaining biodiversity within natural habitats, which is one of the roles provided by GI. For example, species biodiversity offers protection against the spread of certain diseases has been claimed by Zaghi (2010).

Authors like Ganesan (2008) and Kingston (2011) have justified the essence of Biodiversity as a resource for chemical compounds for use in medicine and a number of synthetically-produced drugs are designed to mimic chemicals found in nature. As a means of protecting and promoting biodiversity, GI can therefore contribute to these critical aspects of public health.

Impact of Health related Infrastructure on Promoting Human Health and Social Wellbeing

A growing number of epidemiological studies, for instance articles by Booth (2000), Humpel (2002), Humpel (2004), de Vriers (2003), Payne (1998) and Pikora (2003) indicate that the presence of GI features increases time spent outdoors (independent of age, sex, marital and socio-economic status). This, in turn affects physical health. For example, several studies report a link between the abundance of green space and the self-perceived health of a representative cross-section of inhabitants of a given area. Access to walkable green streets and spaces has also been associated with objective measures of health, such as increased longevity of senior citizens in China and reduced blood pressure and body mass index. These facts have been explained clearly in the articles of Takano (2002), Tanaka (1996) and Orsega-Smith (2004).

Avoiding a sedentary lifestyle has a variety of health benefits, both preventative and restorative. For example, Wannamethee and Shaper (1999), Lee (2001), Sesso (1999), Wei (1999) and Nielsen & Hansen (2007) have explained that increased physical activity associated with access to green spaces is associated with a reduced risk of a stroke, cardiovascular disease and obesity. Availability of nearby GI therefore not only encourages people to take more physical exercise, but also to travel more sustainably by either foot or bicycle through green spaces which has an additional benefit in reducing CO2 emissions produced by other transport has been explained in Moffat (2010).

These epidemiological studies are complemented by a number of controlled experiments, which identify the direct physiological effects of specific human/ecosystem interactions. For example, Hartig (2003) has shown that active contact with nature, i.e. recreational walking in a natural setting, as opposed to an urban environment, has been found to significantly reduce blood pressure. Participating in activities in green settings reportedly improves the functioning of 7-12 year old children with attention deficit disorder has been explained in Faber-Taylor, Kuo and Sullivan (2001). Tzoulas, Korpela and Venn (2007) suggested mechanism for such associations is that emotional changes triggered by nature can induce or mediate physiological changes. This assertion is, in turn, based on the hypothesis that humans have an innate instinct to connect with nature, a theory known as biophilia has been explored in Kellert and Wilson (1993), driven by an evolutionary history of dependence on natural ecosystems for survival. In addition to observations about the positive impact of increased contact with nature, the relationship has also been studied in reverse. For example, Henwood (2002) and Qureshi, Kazmi and Breuste (2010) have shown that environmental stress caused by the removal or deterioration of natural habitat has been linked to chronic anxiety, chronic stress and high blood pressure and the perception of ill-health of inhabitants of Karachi, Pakistan.

Again, GI can contribute significantly to improving air quality and water quality. In summer, absorption of heat by dark surfaces in urban areas, such as concrete rooftops and roads, contribute to the 'urban heat island' effect, which can significantly increase the temperature of urban areas compared to surrounding areas. Excessive heat presents a range of health risks, from fairly benign swelling to potentially fatal heat stroke have been explained in Frumkin (2002). Again, increasing vegetation cover within urban areas, for example, with green roofs and facades, can increase shading and the natural capacity of plants to cool the air by several degrees through evapotranspiration are shown in Pérez, Rincón, Vila, González and Cabeza (2011), Susca, Gaffin and Dell'Osso (2011) and Whitford, Ennos and Handley (2001).

Health benefits of GI exist not just at the individual level, but also at the community, city and even regional levels. Danielsen, Sørensen and Olwig (2005) and Primavera (2005) have argued that natural GI features, such as mangroves, wetlands and forests, protect coastal populations from the damaging effects of storms and sea surges. The maintenance and promotion of such features can protect an area from the damaging effects of natural disasters, decreasing injuries and deaths. For example, mangroves can provide a buffer for the destructive effects of tsunami has been illustrated in Dahdouh-Guebas, Jayatissa and Di Nitto (2005).

Possible Costs Regarding Infrastructure, Human Health and Climate Change

Despite growing evidence of the link between environment friendly infrastructure or green infrastructure (GI hereafter) and public health and wellbeing, the benefits of GI must be weighed up against the social and economic costs, including 'lost opportunity' costs of protecting valuable habitat against land development. Additionally, empirical scientific evidence must be considered in spatial planning decisions to avoid unintended consequences of modifying natural habitat. For example, Cariňanos and Casares-Porcel (2011) have suggested that non-native vegetation and the introduction of invasive species may lead to new pollen allergies emerging in the population, which could counteract the functions that Green Infrastructure aims to provide. However, so far it would seem that weighing such negative consequences or ecosystem disservices up against the reported positive effects indicates that GI brings multiple benefits at comparatively little cost. However, improved scientific understanding of unintended consequences on human health will be necessary to minimise future risks associated with GI implementation.

CLIMATE CHANGE, HUMAN HEALTH AND INTERNATIONAL TRADE

Issues related to human health and climate change in the context of international trade should acquire importance among other hot economic topics. However, we have not found any existing seminal work on the above mentioned issues. Therefore, in this section we are basically trying to integrate human health, climate change and international trade partially, that is initially we will relate human health with international trade and thereafter we shall correlate climate change in the form of environmental degradation with international trade[4].

Human Health and International Trade

Though these do not imply anything directly to the above mentioned topic but this section will help our future researchers not only to obtain existing works on human health and climate change in an open economy but also to know how these socio-economic elements work together. The mismatch between demand and supply of healthcare services and infrastructure has triggered the emergence of private participation in the Indian health sector through FDI. Thus it is become crucial to us to examine the impact of FDI in the health sector[5]. The hypothesis that international trade improves the standard of living is more controversial outside of economies and this issue has been examined by the following articles, namely Wissman (2003), Danaher and Burbach (2000), Chatterjee and Gupta (2014), again the hypothesis that international trade improves living standards from within economies has also been analysed by several articles in the literature, for instance Dollar and Kraay (2004), Chatterjee and Gupta (2015).

Note, studies like Alsan, Bloom and Canning (2006) and Azemar and Desbordes (2009) have addressed the association ship between FDI and health by listing a healthy workforce among the determinants of the location choices of foreign investors.

Again, Wilkinson (2000) has shown that for most developing economies with unequal societies are characterized by relative deprivation and chronic stress is considered to be the main pathway through which inequality impairs health. Moreover, Deaton (2003) has realised and analysed that there are serious questions about whether the correlation between income inequality and health status is robust through time, and whether it comes from the effects of income inequality or some other factors that is correlated with it.

It is to be noted that the long run relationship between FDI and human health for developed countries has been found negative in Herzer and Nunnenkamp (2012).

Environmental Degradation and International Trade

Finally in this section we want to consider the works related to trade and environment. Several works have examined the trade-environment relationship in the last few decades. However, the empirical results reported from these studies appear to be mixed. For example, while the study by Antweiler, Copeland and Taylor (2001) shows that trade liberalization reduces pollution, the findings by Dasgupta, Laplantem, Wang, and Wheeler (2002) appear to be skeptical about the positive environmental effects of trade liberalization. Furthermore, a number of studies such as Suri and Chapman (1998), Mani and Wheeler (1998) find evidence in support of the Pollution Heaven Hypothesis, whereas others such as Grossman and Krueger (1993) and Gale and Mendez (1998) find empirical support in favour of the factor endowment hypothesis and against a significant influence of environmental regulation on trade patterns.

Another issue that has received little attention in the debate on trade-environment nexus is the use of an environmentally adjusted income measure, or an indicator of sustainable development. The very few studies that have employed indicators of sustainable development also report findings that are mixed. For instance, UNEP (1999) and Castaneda (1999) conclude that trade liberalization has a negative impact on the sustainable development of various developing countries, a finding that suggests there might be a trade-off between the economic gains from trade liberalization and its environmental consequences. However, a more recent study by UNEP (2001) finds an overall positive effect of trade on sustainable development for several developing countries.

MITIGATION AND ADAPTATION OF SEVERAL POLICIES, HUMAN HEALTH AND CLIMATE CHANGE

For mitigation of climate change regarding cancer, nuclear power has been suggested as a possible alternative to coal-based power generation. Although Tromp (2003) has revealed that the risks associated with direct exposure to radiation from nuclear power generation have been below accepted danger levels throughout the industry's history, the human health consequences over the full nuclear energy life cycle (production through waste disposal) may be of greater concern.

Again, studies like Frumkin (2008) has shown that mitigation activities regarding Cardiovascular disease[6] such as increasing the density of urban development, enhancing public transportation options, and encouraging alternatives to single occupancy vehicle use are likely to benefit cardiovascular fitness, reducing the overall burden of cardiovascular disease. More research is needed, including economic analyses, to determine the most beneficial strategies to pursue. As with reparatory health risks, risks of cardiovascular disease and stroke may be reduced in urban populations through filtration of ambient pollutants by tree cover, this issue has been clearly mentioned in Bowker (2007). Similarly, Co-benefits of tree cover include heat-island alleviation, reduced energy use to cool buildings, and consequent reductions in greenhouse gas emissions have been explained in Bolund (1999).

While climate change is likely to increase the burden of heat-related illness and death in the United States, many of these outcomes are preventable. McGeehin and Mirabelli (2001) have shown that with aggressive public health actions and widespread physiologic and behavioral adaptations such as robust heat early warning systems and other health communications, increased air conditioning use, decreased time spent outdoors, and increased wearing of sun-shielding clothing it will be possible to reduce overall rates of illness and death, though some of these measures may result in negative health consequences as well.

In regions where water availability is a growing concern, there will be an increasing need to reuse water or seek alternate sources of water that may be of lower quality. This may result in new treatment options that may require the use of additional or more toxic chemicals. Interestingly, Gohlke, Hrynkow, and Portier (2008) have claimed that changes in energy source policies also could increase exposures to numerous airborne metal particulates, many of which, such as lead, have known adverse developmental impacts.

Mitigation to climate change may reduce our reliance on fossil fuels. This reduction in fossil fuel use will reduce the release of a number of neurotoxicants including arsenic, mercury, and other metals into the environment. However, additional mercury releases into the environment might occur due to breakage of these fluorescent bulbs or improper disposal, resulting in human exposures and potential neurological effects. In more complicated mitigation strategies such as the expansion of the use of electric vehicles, heavy metals used in the batteries for such vehicles may present manufacturing and disposal challenges that will be of particular significance to the risk of neurological deficits. These issues have been examined minutely in Bronstein (2009), Gustin (2004) and Noyes (2009).

The potential impacts of different mitigation strategies for waterborne illness depend on the strategy. For instance, Abdel-Wahab (1979)has illustrated that increased hydroelectric power generation will have significant impacts on local ecologies where dams are built, often resulting in increased or decreased incidence of waterborne disease, as was the case with schistosomiasis (increase) and haematobium infection (decrease) after construction of the Aswan Dam in Egypt. Other modes of electric power generation, including nuclear, consume large quantities of water and have great potential environmental impacts ranging from increased water scarcity to discharge of warmed effluent into local surface water bodies. Shifting to wind and solar power, however, will reduce demand on surface waters and, therefore, limit impacts on local water ecosystems and potentially reduce risks of waterborne diseases. The impacts on waterborne pathogen ecology of other geo-engineering mitigation strategies, such as carbon sequestration, have the potential to be substantial but are currently largely unknown have been claimed in White (2005).

Again if the society can find out a certain level of income, up to which one may reasonably expect high greenhouse gas-intensive income growth to affect adversely the climate globally. But beyond this threshold level, climatic degradation can reach a situation where further income growth becomes difficult. Thus, the human race faces the economic as well as social insecurity due to climate change. Climate may act as a constraint to income growth at this latter stage if the greenhouse gas-intensive income growth process is continued. Thus, the global economy faces a serious challenge from the global climate change. To save the world economy or in other way to protect humanity Dinda (2009) has argued that proper environmental policy should be adopted at appropriate time such that we may control the vulnerability of the climate change. It is to be noted that Trade can mitigate the climate change issues of a country, region or the world as a whole. Through international agreement, trade also creates the opportunity for green jobs that produce environment-friendly goods (EFG), which have less damaging impact on environment. This issue has been clearly mentioned in Dinda (2014).

Apart from the above mentioned policies, the policy makers can use the whole of section named '*Infrastructure, Human Health and Climate Change'* as a way through which adverse effects of climate change can be removed somewhat extent[7].

FUTURE RESEARCH AGENDA

This section is most crucial part of this chapter as we are going to mark the research gaps in particular relevant in the context of climate change and human health. In spite of the presence of a large number of existing papers relevant in the context of our above mentioned issues, those we have considered throughout different sections and subsections of this brief literature survey, we cannot explain the following.

1. In the first section we have considered the works related to climate change, human health and social issues, but none of the existing works have explicitly examined the impact of poverty, inequality, etc., on climate change and then it's on human health, especially in the context of mainstream economic analysis.
2. Though the impact of environment friendly infrastructure on climate change and human health has been captured in all of the works those we use in second section of this chapter, but none of them have examined the impact of poor infrastructure health care on climate change.
3. Though there exists quite a few works related to trade and health, even there are few works that have examined the relationship between environment and international trade but there is no single work that have analysed the issues related with human health, climate change and international trade.
4. Lastly but most importantly we find that all the above mentioned research gaps should be examined in the context of lower and middle income economies.

Students with interest in this area can use the above mentioned points as their research agenda in near future to answer the unfolded questions related with climate change and human health.

CONCLUSION

It is clear that climate change should remain an important research agenda, not just for scientists, but also for economists as it can destroy human welfare and human health. This is particularly important for lower and middle income countries, as these economies still suffering from lack of management in social sector in the context of different economic activities, lack of implementation of green infrastructure and poor international coordination. This chapter reviews a number of articles on the issues related to climate change and human health. Initially we have examined the impact of different socio-economic issues on climate change and human health. Moreover, we have collected the works through which one can mitigate the adverse effects of climate change on human health. Issues like poor environment friendly infrastructure or green infrastructure, climate change and health have also been shouted in this study. Again, presence of international trade in the context of our study has also included in this chapter. Finally, the major research gaps and major future research agenda for researchers have been notified at the end of the chapter.

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ENDNOTES

1 For details one can go through intergovernmental Panel on climate change, Working Group ii. (2007).

2 See United states. Congress. Senate. Committee on commerce science and Transportation (2003) for details.

3 See Karl (2009) for details.

4 However, one can argue that why not we use the direct effect of climate change on human health. Actually, we have already mentioned it in the sub-section titled '*What are the ways through which human health can be affected due to climate change?'.*

5 We shall refer to FDI as changes in foreign capital stock and FDI in the health sector as changes in foreign health capital stock. In other words 'usual' foreign capital in this paper is referred to as 'foreign capital' and foreign capital related to health sector is referred to as 'foreign health capital'.

6 Cardiovascular disease refers to a class of diseases that pertain to the heart or blood vessels.

7 For details see the works by Booth *(*2000); Humpel (2002); Humpel (2004); Pikora *(*2003), etc.

Chapter 3
Health Impact of Water-Related Diseases in Developing Countries on Account of Climate Change – A Systematic Review:
A Study in Regard to South Asian Countries

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ABSTRACT

Human health is heavily dependent on clean water resources and adequate sanitation. According to the WHO, diarrhoea is the disease most attributable to quality of the local environment. It has been estimated that 88% of diarrhoea cases result from the combination of unsafe drinking water, inadequate sanitation, and improper hygiene. A meta-analysis has been conducted over the existing literature specifically targeting water-borne and water-related diseases in developing countries. The results are synthesized through the simplest meta-analysis strategy: vote-counting. Given the range of impacts on account of climate change there is an urgent need of proper intervention to counterbalance the expected increase of occurence of water-related illness But given the limited progress in reducing incidences over the past decade consorted actions effective implementation and integration of existing policies is urgently demanded.

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INTRODUCTION

Impacts of Water Related Illness on Health

The Third Assessment Report of the IPCC (IPCC 2001) estimates that globally the average land and sea surface temperature has increased by 0.60 ± 0.2 ^{0}C since the mid-19th century, with much of the change occurring since 1976. Of the many impacts of climate change, those on human health are often placed amongst the most worrying. The impacts of climate change on human health are many and complex. GHG emissions can in principle be considered as risk factor that could potentially be altered by human intervention, with associated effects on the burden of disease.

The increase in the frequency and intensity of extreme temperatures have direct and indirect effects on health. Direct effects include thermal stresses (cardio-vascular and respiratory diseases, heat exhaustion, heat cramps and dehydration), while indirect effects are related to the impact of heat extremes on urban air pollution and humidity (which can aggravate pre-existing morbidity).

Extreme temperatures tends to aggravate pre-existing respiratory and cardio-vascular diseases. In the recent years, extreme weather events, such as floods and landslides, storms, cyclones and droughts, have caused considerable damage and loss of life in China, Venezuela, Bangladesh and Mozambique. Direct impacts of extreme weather events include increased incidence of deaths, physical injuries and psychological stresses, while indirect impacts are related to increased risk of exposure to water-borne diseases due to water contamination, and impacts on malnutrition due to loss in agricultural production. Unsafe water and sanitation conditions and decrease water accessibility would further increase the transmission of infectious diseases (Markandya and Chiabai.,2009).

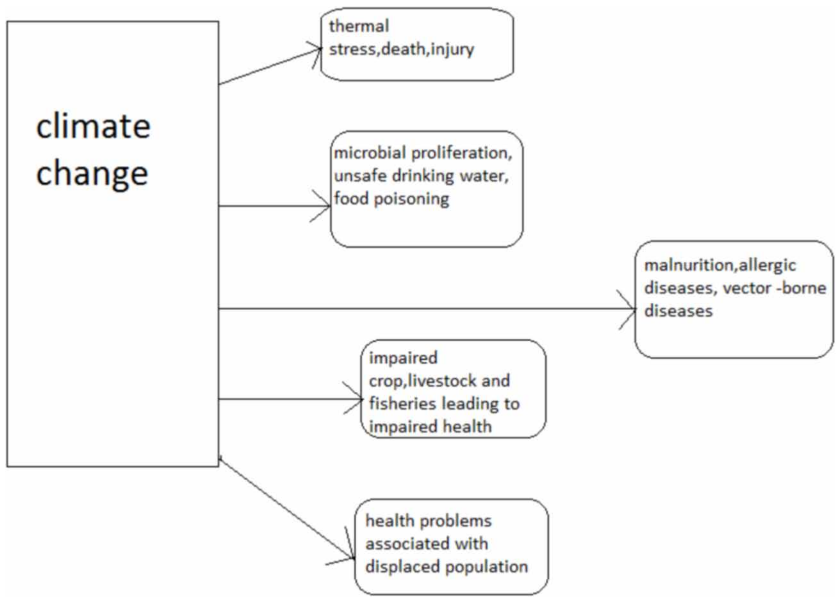
Climate change also leads to outbreak of water-borne diseases, with cholera and diarrhoea being potentially most problematic(McMichael *et al.*, 2006) The Intergovernmental Panel on Climate Change (IPCC) has declared with "very high confidence" that climate change already contributes to the global burden of disease (Confalonieri et al., 2007).

Human health is heavily dependent on clean water resources and adequate sanitation. According to the WHO, diarrhoea is the disease most attributable to quality of the local environment. It is estimated that 88% of diarrhoea cases result from the combination of unsafe drinking water, inadequate sanitation, and improper hygiene (WHO 2006, Pruss-Ustun 2006). Environmental factors account for an estimated 94% of the global disease burden for diarrhoea (WHO 2006), which is a leading cause of death among children. One of the main sources of diarrheal disease is contamination by faecal-oral pathogens that are largely caused by a lack of safe drinking water and sanitation facilities. Additionally, inadequate sanitation poses threats to the environment from improper disposal and treatment of human waste. It is important for populations to have access to drinking water and adequate sanitation because these factors play large roles in human health.

The IPCC summarized the main health impacts as follows:

- Increases in malnutrition and consequent disorders, with implications for child growth and development
- Increased death, disease and injury due to heat waves, floods, storms, fires and droughts
- Increased burden of diarrhoeal diseases
- Increased frequency of cardio-respiratory diseases due to higher concentrations of ground level ozone related to climate change
- Altered spatial distribution of some infectious disease vectors.

Figure 1. Impacts of climate change on human health



According to Haines et al(2006) research studies on the health impacts of climate change addresses three main topics- current associations between climate and disease; the effect of recent changes in climate; and the evidence base for projecting the future impacts of climate change on health.

The impact of climate change on human health vary greatly depending on many variables including the behaviour, age, gender, race, and economic status of individuals. Moreover, such variables can also be expanded to include region, the sensitivity of populations, the extent and length of exposure to climate change, and society's ability to adapt to change. People living in small islands and coastal regions, megacities, and mountainous and polar regions are particularly prone to such degrading environmental conditions. McMichael et al (2000) inferred that the effects of global climate change are predicted to be heavily concentrated in poorer populations at low latitudes, where the most important climate-sensitive health outcomes (malnutrition, diarrhoea and malaria) are already common, and where vulnerability to climate effects is greatest affecting mostly the younger age groups.

Likewise, children living in poor countries, the elderly, and those with infirmities or pre-existing medical conditions will be affected most sensitively by these alterations.

Figure 1 gives us an overview of the impacts of climate change on human health and what sort of mitigation and adaptive measures are required to resolve the problem.

Though different studies have tried to address the impacts of climate change on human health but as per IPCC(2014) there lies important research gaps regarding the health consequences of climate change and co-benefits actions, particularly in low-income countries.

Human health therefore figures prominently in assessments of the impacts of climate change. The welfare costs (or benefits) of health impacts contribute substantially to the total costs of climate change (Cline, 1992; Fankhauser, 1995; Tol, 2002). The majority of estimates of the economic damages of global warming rely on the methodology of direct costs, that is, damage equals price times quantity. In case of human health, the price is typically equal to the value of a statistical life, which is based on estimates of the willingness to pay to reduce the risk of death or diseases, or the willingness to accept compensation for increased risk (Viscusi and Aldy, 2003).

Benefits of Quantification of Health Impacts of Water Pollution and Valuation

Climate change in regard to water pollution is also posing risks to human population health and well-being and thus is emerging as a serious concern worldwide (Kovats and Haines, 2005,Tol 2008., Stern.,2007) . In 2000 climate change was estimated to be responsible for approximately 2.4% of worldwide diarrhoea and 6% of malaria. According to the IPCC third assessment report the world temperature is expected to further rise during the century, implying increased health threats for human populations, especially in low-income countries.

According to Markandya and Chiabai (2009) Asia, Africa, Small island developing states and North America are mostly affected by water-borne diseases on account of climate change.

Reviewing the US literature addressing health impacts of climate variability and change Ebi et al.(2006), conclude that climate change is expected to increase morbidity and mortality risks from climate-sensitive health outcomes such as extreme heat events, floods, droughts and fires. A spread in vector–borne diseases, like malaria, is also expected (Remoundou and Koundouri, 2009).It follows from WHO(2004)that Diarrhoeal diseases account for 1.81 deaths in millions. Checkley et al. (2000) observed that daily hospital admissions for diarrhoea exhibited a twofold increase per 5 °C increase in the mean ambient temperature. Diarrhoea outbreaks are related to periods of heavy rainfall and runoff when subsequent turbidity compromises the efficiency of the drinking water treatment plants.

According to WHO(2004), diarrhoea is responsible for the loss of 73 million DALYs, acute respiratory tract infection for 95 million DALYs, malnutrition for 39 million DALYs and neglected tropical diseases for 19 million DALYs; all of which are directly or indirectly related to sanitation. Worldwide, diarrhoea, acute respiratory infections, malaria and immunizable diseases account for 70% of the deaths among children aged 0–4 years. It also suggests diarrhoeal diseases caused by inadequate access to safe water, lack of sanitation and poor hygiene may contribute up to 10% to the total burden of disease.In the context of South Asian countries there lies a significant relation between impact of climate change and incidence of water-related illnesses.

Climate change is by and large a relatively distal risk factor for ill-health, often acting through complex causal pathways which result in heterogeneous effects across populations.

Table 1. Health determinants and health outcomes existing in South Asian Countries

Events of Climate change	Bangladesh	Bhutan	Nepal	India	Sri Lanka
Malaria	Yes(NM)	Yes(NM)	Yes(T)	Yes(NM)	Yes(NM)
Dengue	Yes(NM)	Yes(NM)	No	Yes(NM)	Yes(NM)
Water-borne diseases	Yes(NM)	Yes(T)	Yes(T)	Yes(T)	Yes(T)
Water scarcity, quality	Yes(NM)	Yes(NM)	Yes(M)	Yes(M)	Yes(M)

Source: WHO(2005)
M=Mountainous, NM= Non-mountainous

Valuation Techniques for Measuring Health Impacts

Quantifying the range of human health impacts on account of climate change have been undertaken in the recent past.

Various methods have been in the literature for the estimation of health outcomes of climatic change (Martens and McMichael 2002; McMichael and Kovats 2000). Gap still prevails regarding future projections on observed long-term climate trends due to lack of standardized long-term monitoring of climate-sensitive diseases in many regions, methodological difficulties in measuring and controlling for non-climatic influences on long-term health trends. The changes that have occurred so far are an inadequate proxy for the larger changes that are to forecast for coming decades.

Several studies has tried to address the issue of health impact on account of water pollution but a handful had tried to focus on specifically addressing the issue of water related and water borne illnesses on account of climate change(Markandya and Chiabai.,2009,Kim et al.,2014, McMichael et al.,2004,McMichael et al.,2006,Molla et al., 2006)

There are two alternative strategies generally undertaken for valuing environmental change affecting human health. The first strategy is to develop a comprehensive model of individual behaviour and choice in which environmental quality is one of the determining variables where such models will help in estimating willingness to pay as a functional of change in environmental quality. The second strategy is to deal with the two links separately. Economic values of changes in health risks would be derived and then that will be combined with independently derived predictions of health changes or risk changes as a function of environmental change.

Cost-effectiveness analysis (CEA) which is a technique for least cost intervention, which enables us to define priorities among different alternative interventions by identifying the least cost option to reach the underlying objectives. CEA is sometimes used as a second-best option when a full-blown Cost-Benefit Analysis (CBA) would be desirable, but many benefits cannot easily be monetized (Ortiz., 2005).

The cost-effectiveness ratio of a program is computed by dividing the annualized costs of the program by the physical benefits, measured in terms of lives saved (or life years saved), and cases of illness avoided. Results are expressed as unit costs, in terms of costs to be supported to save one life (or one year life) and to avoid one episode of illness. If all else is the same, the program deemed more cost-effective would be the one with the lowest cost per life saved or avoided case

In the context of climate change CEA is a useful tool to provide a measure of the costs of a program in terms that are comparable across programs. Studies on the costs of adaptation programs are indeed difficult to compare in a way that provides some guidance on whether they are justifiable or not (Markandya and Chiabai, 2009).

Remoundou and Koundouri (2009) in their study addresses on the main approaches for health impact valuations which can be broadly classified into revealed and stated preference techniques. Revealed preferences include cost of illness, human capital surveys, hedonic pricing and the Quality Adjusted Life Year studies or stated preference studies preferably the Contingent Valuation Method (CVM) and the Choice Experiments (CE).

As a researcher it becomes difficult in making a choice between various valuation techniques that exist in the literature as different estimation techniques have their own strengths and weaknesses. Given that limitation as well as time and budget constraints different studies had tried to capture the impacts on human health on account of water pollution.

Diener et al(1998) conclude that studies undertaking contingent valuation should distinguish between compensating variation and equivalent variation, and recognize that respondents can be gainers or losers in utility and therefore should be asked willingness-to-pay (or accept) questions as appropriate. Current critical-appraisal guidance in the health care literature for CBA is poor and unlikely to offer useful demarcation between good and bad CBA studies. More work is needed exploring whether recently issued guidelines for contingent valuation in environmental damage assessment are applicable to health care studies.

Since primary data collection to establish the dose response functions or proceed with the valuations can be expensive and time-demanding, there is substantial policy interest in using benefit transfer techniques in the recent days. In this context, original values from existing studies are transferred to policy sites after correcting for certain parameters. Given the number of valuation studies, several meta-analyses studies have been popular in the recent past. Following this approach valuation estimates from existing studies are collected and the determinants of these estimates are examined. Meta-analyses can feedback the establishment of value transfer functions to estimate values for policy sites of interest based on properly adjusted information from existing studies on similar sites, study sites.

Diener et al., (1998) implemented meta-analysis in the context of CVM for valuing health care. 48 CVM studies were retrieved. It has been observed that the number of health care CVM studies is growing rapidly and the majority are done in the context of CBA. Moreover there is a wide variation among health care CVM studies in terms of the types of questions being posed and the elicitation formats being used. The classification and appraisal of the literature is difficult because reporting of methods and their relationship with the conceptual framework of CBA is poor.

There has been, however, been no formal systematic review specifically targeting the impact of climate change and health impacts in the context of water pollution except Fewtrell and Colford(2004) and Fewtrell et al., (2005).

We present a systematic review of all published studies where the occurrence of diarrhoeal disease has been considered as an impact of climate change. Other than that the review also incorporates studies which had adopted several interventions/ adaptive measures to minimise the occurrence of water-related illnesses in less developed countries and developing countries.

Diarrhoeal diseases are highly sensitive to climate, showing seasonal variations in numerous sites (Drasar et al. 1978). Diarrhoeal disease is one of the leading causes of morbidity and mortality in developing countries, especially among children under the age of five (Kosak *et al*., 2003; Prüss *et al*., 2002)

Climate-sensitivity of diarrhoeal disease is consistent with observations of the direct effects of climate variables on the causative agents. It has been observed that temperature and relative humidity have a direct influence on the rate of replication of pathogens, and on the survival of entero viruses in the environment. Studies like Eberhead et al., 1999, Purohit et al., 1998 describe climate effects on particular diarrhoea pathogens.

LITERATURE REVIEW

A literature review search has been conducted to survey studies on the area of health impacts due to climate change over the years. Very few papers had targeted to address the health impacts on account of water pollution as a result of climate change. Some of the key papers have been discussed as follows.

Purohit et al (1998) was one of initial studies in India tried to conceptualize relation between seasonal variation and occurrence of diarrhoea. Box-Jenkins methodology was employed for the analysis. The model suggested a strong influence of climatic changes on the incidence of the disease. Further study of weather parameters not only confirms that daily minimum temperature is the principal factor but also revealed that easterly wave is useful in predicting the peak of hospital admissions and the geographical sequence of outbreaks of the disease in tropical India.

Singh et al (2001) carried out two related studies in Pacific Islands to explore the potential relationship between climate variability and the incidence of diarrhoea. In the first study, they examined the average annual rates of diarrhoea in adults, as well as temperature and water availability from 1986 to 1994 for 18 Pacific Island countries. There was a positive association between annual average temperature and the rate of diarrhoea reports, and a negative association between water availability and diarrhoea rates. In the second study, they examined diarrhoea notifications in Fiji in relation to estimates of temperature and rainfall, using Poisson regression analysis of monthly data for 1978-1998. There were positive associations between diarrhoea reports and temperature and between diarrhoea reports and extremes of rainfall.

Bosello et al (2004) tried to quantify economy-wide impacts on human health due to climate change. Here they estimated the economic effects of human health impacts, and compare these to the direct welfare costs. In order to assess the systemic, general equilibrium effects of health impacts, induced by the global warming, they made an unconventional use of a standard multi-country world CGE model: the GTAP model. For diarrhoea, they report the estimated relationship between mortality and morbidity on the one hand and temperature and per capita income on the other hand, using the WHO Global Burden of Disease data. GDP, welfare and investment fall (rise) in regions with net negative (positive) health impacts.

Fewtrell and Cohord (2004) conducted a systematic review on intervention through improvements in drinking water, sanitation and hygiene facilities and diarrhoea. All interventions reduced diarrhoea morbidity, with pooled risk ratios ranging from 0.98 to 0.51 (where a risk ratio of 1.0 indicates no effect and lower risk ratios indicate stronger effects). The removal of poor quality studies from the analyses improved the strength of the intervention impact in most cases. The 95% confidence intervals (CIs) for the pooled risk ratios of various interventions overlapped, indicating their effects were not statistically significantly different from each other. In developing countries, water quality interventions, specifically point-of-use treatment, reduced diarrhoeal illness levels. Water supply interventions reduced diarrhoea, but this effect was mainly seen with the provision of household connections and use of water without household storage. Hygiene interventions, especially those promoting hand-washing, were effective. Only limited data were available for sanitation interventions, but these suggested effectiveness in reducing diarrhoea. Multi-factorial interventions consisting of water supply, sanitation and hygiene education acted to reduce diarrhoea but were not more effective than individual interventions. Relatively few studies examined interventions in established market economies. Those that did supported the effectiveness of hygiene interventions, sanitation, and water supply.

McMichael et al (2004) analyses suggested that climate change will bring some health benefits, such as lower cold-related mortality and greater crop yields in temperate zones, but these will be greatly outweighed by increased rates of other diseases, particularly infectious diseases and malnutrition in developing regions. Climate change was estimated to increase the relative risk of diarrhoea in regions made up mainly of developing countries to approximately 1.01–1.02 in 2000, and 1.08–1.09 in 2030. Richer countries (GDP >US$6000/year), either now or in the future, were assumed to suffer little or no additional risk of diarrhoea. Overall, the effects of global climate change are predicted to be heavily concentrated in poorer populations at low latitudes, where the most important climate-sensitive health outcomes (malnutrition, diarrhoea and malaria) are already common, and where vulnerability to climate effects is greatest. The children are found to be the worst sufferers.

Fewtrell et al (2005) conducted meta-analysis on only those articles with specific measurement of diarrhoea morbidity as a health outcome in non-outbreak conditions 46 studies were extracted to provide summary estimates of the effectiveness of each type of intervention. All risk estimates from the overall meta-analyses ranging between 0·63 and 0·75. Water quality interventions (point-of-use water treatment) were found to be more effective than previously thought, and multiple interventions (consisting of combined water, sanitation, and hygiene measures).

Hashizume et al (2008) identifies groups vulnerable to the effect of flooding on hospital visits due to diarrhoea during and after a flood event in 1998 in Dhaka, Bangladesh. The number of observed cases of cholera and non-cholera diarrhoea per week was compared to expected normal numbers during the flood and post-flood periods, obtained as the season-specific average over the two preceding and subsequent years using Poisson generalised linear models. During the flood, the number of cholera and non-cholera diarrhoea cases was almost six and two times higher than expected, respectively. In the post-flood period, the risk of non-cholera diarrhoea was significantly higher for those with lower educational level, living in a household with a non-concrete roof, drinking tube-well water (vs. tap water), using a distant water source and unsanitary toilets.. The low socio-economic groups were most vulnerable to flood-related diarrhoea.

Tseng et al (2009) estimated economic impacts of climate change for dengue fever in Taiwan. Results indicate that people are willing to pay € 15.78, € 70.35 and € 111.62 per year in order to reduce the probabilities of dengue fever inflection by 12%, 43%, and 87%, respectively.

Chou et al (2010) investigated and quantified the relationship between climate variations and diarrhoea-associated morbidity in subtropical Taiwan. It addresses the local climatic variables and the number of diarrhoea-associated infection cases from 1996 to 2007. The study applied a climate variation-guided Poisson regression model to predict the dynamics of diarrhoea-associated morbidity. The variables incorporated in the model includes relative humidity, maximum temperature and the numbers of extreme rainfall, auto-regression, long-term trends and seasonality, and a lag-time effect. Results indicated that the maximum temperature and extreme rainfall days were strongly related to diarrhoea-associated morbidity. The impact of maximum temperature on diarrhoea-associated morbidity appeared primarily among children (0–14 years) and older adults (40–64 years), and had less of an effect on adults (15–39 years). Thus the children and older adults were the most susceptible to diarrhoea-associated morbidity caused by climatic variation. Policy measures as suggested in the study is to develop an early warning system based on the climatic variation information for disease control management.

Fadel et al (2012) attempts to quantify climate-induced increases in morbidity rates associated with food- and water-borne illnesses in Beirut-Lebanon. A Poisson generalized linear model was used to assess the impacts of temperature on the morbidity rate. The model was used with four climatic scenarios to simulate a broad spectrum of driving forces and potential social, economic and technologic evolutions. The correlation established in this study exhibits a decrease in the number of illnesses with increasing temperature until reaching a threshold of 19.2°C, beyond which the number of morbidity cases increases with temperature. By 2050, the results show a substantial increase in food- and water-borne related morbidity of 16 to 28% that can reach up to 42% by the end of the century.

Another study Moors et al (2013) in regard to the impact of future climate change on diarrhoea incidences in India. The study has been conducted in the Ganges basin of northern India. A conceptual framework was used for climate exposure response relationships based on studies from different countries, as empirical studies and appropriate epidemiological data sets for India were lacking. The climate variables for the study were- temperature, increased/extreme precipitation, decreased precipitation/droughts and relative humidity. Applying the conceptual framework to the latest regional climate projections for northern India shows increases between present and future (2040s), varying spatially from no change to an increase of 21% in diarrhoea incidences, with 13.1% increase on average for the Ganges basin. They suggested three types of interventions against diarrhoeal disease: reactive actions, preventive actions and national policy options.

Veronesi et al (2014) applied discrete choice experiment technique to predict for climate change scenarios which will lead to extreme rainfall and wastewater overflow and associated health risks study elicits the willingness to pay to reduce ecological and health risks from combined sewer overflows in rivers and lakes, and wastewater flooding of residential and commercial zones under the uncertainty of climate change. We implement a discrete choice experiment on a large representative sample in Switzerland. 71% of the respondents are willing to pay a higher annual local tax to reduce the risk of sewage overflows in rivers and lakes. Swiss households had also strongly valued the protection of water bodies, and mostly, the avoidance of high ecological risks and health risks for children in rivers and lakes. The findings also show that climate change perception has a significant effect on the willingness to pay to reduce these risks.

METHODOLOGY

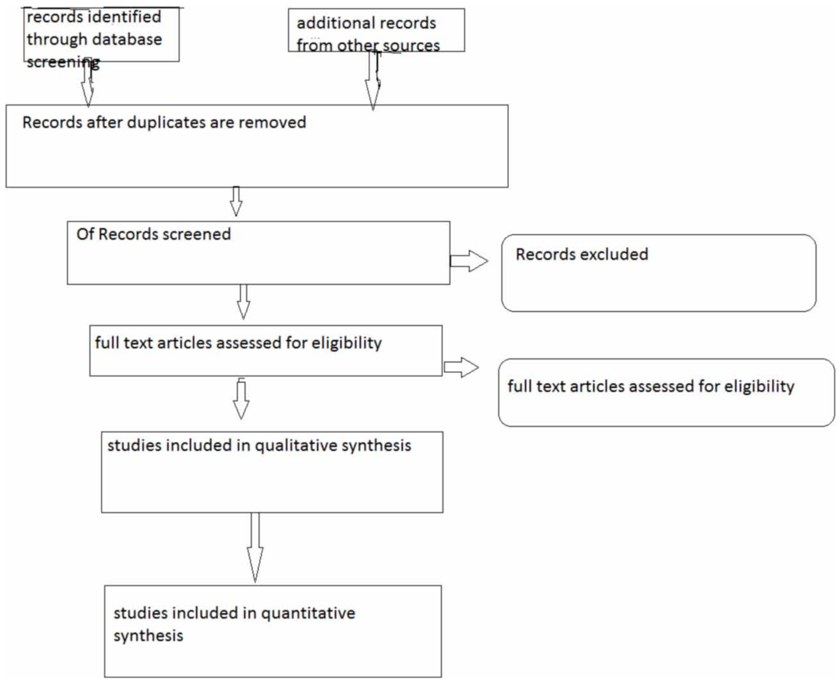
The meta-analytical approaches provide a series of techniques that allow the cumulative results of a set of individual studies to be pulled together. It permits a quantitative aggregation of results across studies. Hunter et al(1982) argue that 'what is needed are methods that will integrate results from existing studies to reveal patterns of relatively invariant underlying relations and causalities, the establishment of which will constitute general principles and cumulative knowledge.

Meta-analysis was first proposed by Glass (1976) as a method for the systematic quantitative summary of evidence across empirical studies. It currently enjoys widespread use in several areas, including the health sciences, psychology, education, marketing, and the social sciences. Application of meta-analysis in economics began in 1989-1990 with studies by Stanley and Jarrell (1989), Jarrell and Stanley (1990), Smith and Kaoru (1990), Walsh et al. (1989, 1990), and Weitzman and Kruse (1990). Several hundred analyses have been prepared in economics, with at least one-third in the area of environmental and resource economics. Smith and Pattanayak., 2002 in their study compiled a list of non- market valuation studies in environmental economics for meta- analyses. Lewis and Pattanayak (2012) conducted a systematic review of the literature on the adoption of improved cook stoves or a movement up the energy ladder from dirty to clean fuel for households in developing countries through vote-counting.

An important criticism of the use of meta-analysis in the field of environmental valuation is that it compares findings from studies which are not the same. Including studies employing different standards of design or measurement will undermine the inferences made from a cross-analysis. There has to be a variation somewhere, besides statistical errors, in order to be able to explain differences in outcomes. The core question becomes therefore whether the analysis is appropriate for testing different findings derived by intrinsically different measures.

The simplest of the meta-analytical methods is vote-counting, in which the investigator categorizes findings as significantly positive, significantly negative or not significant for each variable (e.g. pollutants). The category with the most entries

Figure 2. Flow of information through different stages of systematic review



is then considered the best representation of the relationship between the dependent variable and each of the explanatory variables of interest.

In this method, the investigator gathers all the relevant studies and then constructs one or more indicators of the relationships under investigation from each study.

Hedges and Olkin(1985) pointed out that the traditional vote-counting or box-score methodology uses the outcome of the test of significance in a series of replicated studies to draw conclusions about the magnitude of the treatment effect

In 1996, to address the suboptimal reporting of meta-analyses, an international group developed a guidance called the QUOROM Statement (Quality Of Reporting Of Meta-analyses), which focused on the reporting of meta-analyses of randomized, controlled trials. PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses), which have been updated to address several conceptual and practical advances in the science of systematic reviews. Moher (2009) reports different stages for a systematic review.

Before including studies and providing reasons for excluding others, the review team must first search the literature. This search results in records. Once these records have been screened and eligibility criteria applied, a smaller number of articles will remain. The number of included articles might be smaller (or larger) than the number of studies, because articles may report on multiple studies and results from a particular study may be published in several articles.

By counting up the number of votes across the studies, we can identify a general relationship for that specific variable. As such, vote counting provides a useful starting point for a systematic assessment of studies within a given research area, and has been popular in medicine and natural resource management. The number of studies falling to each of the categories is then tallied. In this method, the investigator gathers all the relevant studies and then constructs one or more indicators of the relationships under investigation from each study.

While refining our search criteria specifically targeting impacts of health impacts of climate change resulting in water borne diseases, it is very difficult to refine our search as very few papers related to health impacts as a result of water-borne diseases has specifically mentioned the issue of climate change. We tried to consider found in more recent literature searches. However the field of research is relatively new and expanding rapidly.

We initially tried to incorporate the studies in PubMed database with key word searches " economic valuation" "water quality", "access to proper sanitation and hygiene" against 'diarrhoea' and "climate change" .An additional series of searches paired 'sanitation', 'safe drinking water', and 'hygiene' against 'intervention'. The search was further refined by using "developing countries" and "South Asian countries"

The criteria "regression analysis" "economic valuation" were excluded as the number of studies turned out to be negligible in regard to climate change and water-related illnesses.

The following selection criteria were used to identify articles:

1. Description of reporting water related and water-borne illness on account of climate change
2. Studies done in the developing and under-developed countries specifically the South Asian countries
3. Diarrhoea/ Cholera morbidity reported as the health outcome, measured under endemic (non-outbreak) conditions.
4. The studies are conducted within 10-15 years.

Both peer-reviewed journal and grey literature was also included to avoid publication bias. Our search criteria ended in having 25 studies.

Data were extracted, wherever available from the selected studies. It include-

Study location (country and urban/rural population);

- Study type;
- Year of study
- Sample size
- Data collection method

For the studies related to intervention further we took into consideration the aspect of

- Type of intervention-
  - Hygiene interventions
  - Sanitation interventions
  - Water quality interventions
  - Multiple interventions

The data from the studies are pooled together and vote- counting has been used for each of the variables selected –whether they happen to be positively, negatively significant or insignificant.

Table 2 gives an overview of the studies selected by systematic review.

The data are also extracted separately from the studies which account for some interventions to minimise water-related illnesses (see Table 3).

LIST OF VARIABLES

Increase in Temperature

A warmer climate could cause water-borne diseases to become more frequent, including cholera and diarrhoeal diseases such as giardiasis, salmonellosis, and cryptosporidiosis. Diarrhoeal diseases are already a major cause of morbidity and mortality in South Asia, particularly among children. It is estimated that one-quarter of childhood deaths in South Asia are due to diarrhoeal diseases. As rising ambient temperatures increase,

Table 2. Number of studies selected by search-criteria

Author	Year of Publication	Country/Location	Survey Technique	Year of Data
Dhara et al	2013	India	Preview	-
Diener et al	1998	-	Meta-Analysis	-
Tseng et al	2009	Taiwan	Preview	
Bosello et al	2004	Different regions of the world	CGE using GTAP	2050
Adamowicz et al	2004	Canada	Choice experiment	2004
Benova et al	2014	-	Meta-Analysis	-
Amr and Yasin	2008	Gaza strip	Historical data and interview questionnaire	2000-06
Azizullah et al	2011	Pakistan	Meta-Analysis	
Chou et al	2010	Taiwan	climate variation-guided Poisson regression model	1996-2007
Fadel et al	2012	Beirut-Lebanon	Poisson generalized linear model	2001-10
Hashizume	2007	Bangladesh	Poisson generalized linear model	-
Hashizume	2008	Bangladesh	Poisson generalized linear model	1998-2008
Singh	2001	Pacific Islands	Poisson generalized linear model	1986-1994
Checkley et al	2000	Peru	Time series model	1993-98
Checkley	2003	Peru	Birth cohort	1995-98
Fewtrell	2005	-	Meta-Analysis	
Halvorson et al	2008	Mali		2008
Luby et al	2011	Bangladesh	500 intervention and 500 control intervention	2007
Moors et al	2013	India	Regional climate model simulations	2013-2040
Cama et al	1999	Peru	Odds ratio	1995-97
Pinfold et al	1991	Thailand	Charts/Simple calculations	1982-87
Saidi et al	1997	Kenya	Hi square, t test	1991-93
Purohit et al	1998	India	Box-Jenkins	1992-96
Fewtrell and Colford	2000	-	Meta analysis	-
McMichael et al	2004	-	Meta Analysis	-
Bhandari	2013	Nepal	Time-series analysis	1998-2001

Source: Authors' own compilation

bacterial survival time and proliferation and thus the incidence of diarrhoeal diseases might further increase.

Diarrhoeal diseases are largely attributable to unsafe drinking water and lack of basic sanitation; thus, reductions in the availability of freshwater are likely to increase the incidence of such diseases. Rapid urbanization and industrialization, population growth, and inefficient water use are already causing water shortages in India, Pakistan, Nepal,

Table 3. Number of studies selected on types of intervention

Author	Year of Publication	Country/Location	Survey Technique	Type of Intervention
Lee et al	1991	Thailand	RR	Hygiene
Pinfold et al	1996	Thailand	RR	Hygiene
Shahid et al	1996	Bangladesh	IDR	Hygiene
Daniels et al	1990	Lesotho	OR	Sanitation
Sathe et al	1996	India	RR	Water quality
Xiao et al	1997	China	RR	Water quality
Cama et al	1999	Peru	OR	Water quality
Sobsey et al	2003	Bangladesh	IDR	Water quality
Aziz et al	1990	Bangladesh	IDR	multi intervention
Mertens et al	1990	Sri lanka	IDR	Multi intervention
Hoque et al	1997	Bangladesh	RR	Multi intervention
Nanan et al	2003	Pakistan	OR	Multi intervention

Source: Fewtrell et al(2005),Fewtrell and Colford, own compilation

and Bangladesh. Climate change will exacerbate the lack of available fresh water as annual mean rainfall decreases in many areas.

Extreme Rainfall

Floods are low-probability, high-impact events that overwhelm physical infrastructure, human resilience, and social organisation. Floods result from the interaction of rainfall, surface run-off, evaporation, wind, sea level, and local topography. In inland areas, flood regimens vary substantially depending on catchment size, topography, and climate.

Relative humidity have a significant effect on the occurrence of diarrhoea(Hazizume.,2008). Other variables include the socio-economic factors like income, age, and children.

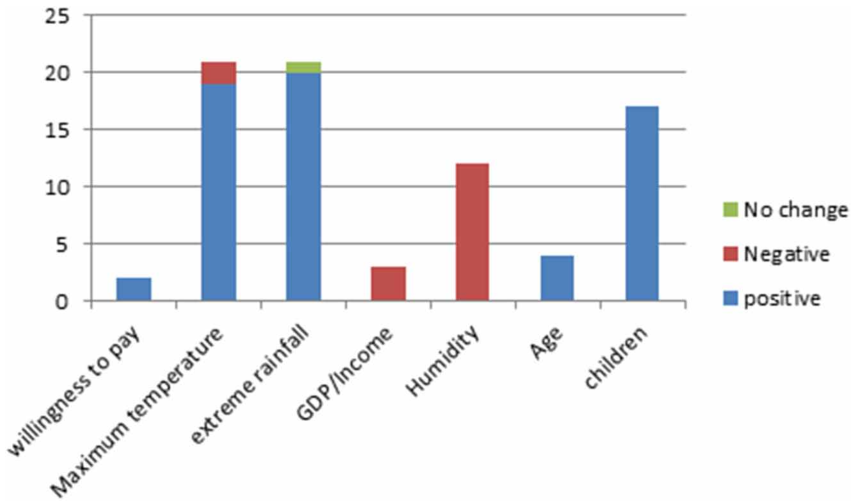
Figure 3 compiles the results obtained from vote-counting of the selected studies. Out of the selected studies only 2 studies had applied stated preference technique where the consumers are willing to pay for water related illness on account of climate change.

Almost all the studies are positively significant for maximum temperature and extreme rainfall.3 studies are negatively significant for the variable GDP/level of income with health impact. The number of sick days lost adversely affects the level of income at household level and in an aggregate level has a negative impact on the country's GDP. 12 studies had stated of the negative impact of level of humidity on health. Lastly the variable age is positively significant. The age group (0-5) and the old age people are more vulnerable to climate change impacts and water related illnesses. The children are more affected as a result of occurrence of water-related illnesses on an account of climate change.

Intervention Related Variables

Hygiene intervention includes handwashing with soap and hygiene education. Sanitation intervention includes provision of latrines, water quality intervention includes treatment of water and multiple interventions include all taken together. For all the studies in South Asian countries hygiene,

Figure 3. Vote counting of the selected studies over occurrence of illness



improvement in water quality as well as combinations of multiple interventions significantly minimises the occurrence of diarrhoea.

Policy Implications and Conclusions

Quantification of health impacts from specific risk factors, derived from a systematic review of cross-country studies provide a powerful mechanism for comparing the impacts of various risk factors and diseases. It allows us to begin to answer questions like -on aggregate impact, how important is climate change more vulnerable to health risk compared other risk factors for global health? How much of the disease burden could be avoided by mitigating climate change? Which specific impacts are likely to be most important and the affected regions?

Gaps may still persist in quantifying such impacts by such a systematic review as each valuation tool has its own limitations and the actual situation may vary from inference we derive from studies in that area.

On the other hand,in order to cope with the adverse health effects of climate change, adaptation measures, plans and programs are needed.

Table 4. Economic benefits from improved sanitation

Beneficiary	Direct Economic Benefits of Avoiding Diarrhoeal Disease	Indirect Economic Benefit on Account of Health Improvement	Non-Health Benefits Due to Improved Sanitation
Health sector	Less expenditure on diarrhoeal disease	Value of less health workers falling sick with diarrhoea	More carefully managed on water environment and effect on vectors
Patients	Less expenditure on diarrhoeal diseases and related cost Less expenditure on transport in seeking treatment Less time loss due to treatment seeking	Value of avoided days lost at work Value of loss of death	More carefully managed water environment and effect on vectors
Consumers			Time-saving for better access to water and sanitation Switch away from more expensive water sources Rise in property value Leisure activities and non-user value

Adaptation is defined in terms of "policies, practices, and projects with the effect of moderating damages and/or realizing opportunities associated with climate change".

Though there lies significant benefits from possible interventions like better sanitation there involve significant costs for interventions (See Table 4). Ebi(2008) tried to estimate the costs of specific interventions for treatment of additional cases of malaria, diarrhoea and malnutrition expected between 2000-2030, due to climate change. It concludes that additional annual costs will be around US$ 3-8 billion for malaria and US$ 3-9 billion for diarrhoea worldwide. For diarrhoea, Markandya and Chiabai(2009) suggested structural intervention can be implemented which provide also considerable non-health benefits. The costs of improved water and sanitation, require huge investments to meet the MDGs, result in costs per case avoided that are fairly low.

In order to give a rational basis for prioritizing policies, at the least it is necessary to obtain an approximate measurement of the likely magnitude of the health impacts of climate change. Integrating environmental, public health, and meteorological observations to real-time public health issues, along with efforts to downscale long-term climate models should be effectively and efficiently put together to accurately estimate human exposure risks and burden of disease.

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Chapter 4
Heat Stress Vulnerability among Indian Workmen

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ABSTRACT

The average global temperature increase is estimated to go up by 1.8-4.0 ^{0}C by the next century. This climate change ought to affect populations where the burden of climate-sensitive disease is high – such as the urban poor in low- and middle-income countries. Particularly in industrial applications, heat generates during manufacturing process. This heat transmits to the environment to make it hotter, as well as the community, especially affecting workers involved in the operation. The primary outcomes of working in such environment leads to three kinds of major heat-related disorders-heat cramps, heat exhaustion and heat stroke. Understanding the quantifiable volume of health impacts due to work habits in hot working environment would provide multiple avenues of suitable intervention. Elucidating the multiple avenues of work pattern, physical and physiological attributes would generate knowledgebase and yield numerically defined susceptibility limits of workers occupational front. The present chapter provides directions to research into the heat related health profile of Indian workmen which would ascertain the relative vulnerability of different occupational groups to their workplace heat eventuality.

BACKGROUND

Climate change threatens human health and well-being in many ways including extreme events, and wildfires, increased frequency and intensity of heat waves, decreased air quality and disease transmitted by insects, food and water. Out of many topics related to climate change we focused on heat stress vulnerability at the occupational front, particularly in developing countries like India. Despite understanding that human being has enormous physiological and psychological

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potentials to combat work pressure demand, environmental adversities etc., resilience and capacity to cope up with the impacts of such exposure is limited. This subject would sensitize the policy makers to the exposed population to be aware of the prevailing circumstances as well as nurture the possibilities of mitigating the situation.

As per Census 2011, there are circa 482 million active workforce in India. It is also accounted that above 9/10th of the workforce work in the unorganized sector. Being in this unorganized sector, they get paid either on daily basis or on the basis of production output. Although these workers understand that working in such environment for long would result in gamete of health issues, they continue to work for long hours. This is because they understand that work intensity gets reduced due to heat exposure, their hourly output gets effected and consequently the income. Avoiding such reduction in income, working people keep up their work intensity or work for long hours which in turn stimulate risk of serious health effects of heat.

The World Health Organization estimates occupational health risks as the fifteenth leading cause of morbidity and mortality. Working under extreme environmental heat load along with a variety of hazards viz. chemicals, biological agents, physical factors, adverse ergonomics, allergens, complex network of safety risks, varied psychosocial factors etc. result in range of health outcomes, injuries, hearing loss, respiratory, musculoskeletal, cardiovascular, reproductive, neurotoxic and psychological disorders. Occupational risk factors account globally for a number of morbid conditions, including 37% of back pain, 18% of injury, 16% of hearing loss, 12% of deaths due to chronic obstructive pulmonary diseases, 8% occupational lung cancer. Above 9/10th of this injury burden is among men and half of the global burden occurs among men in the WHO South-east Asia and West Pacific regions. The burden of disease from selected occupational risk factors amounts to 1.7% of the global burden in terms of DALY (Disability Adjusted Life Years) (WHO, 2009). Enriching the 2009 data, WHO reports that respiratory diseases (59.8%) and musculo-skeletal disorders (56.4%) are the leading occupational diseases followed by noise induced hearing loss (40.2%) (WHO, 2013).

Therefore, workplace heat is a serious concern in regards to the health of the workers. Research into the heat stress vulnerability, intervention strategies and most importantly legislative enforcement of appropriate work-rest cycle would lower down the heat stress vulnerability of the working population.

INTRODUCTION

The climate all around the globe is experiencing a non-steady, increase in temperature, frequency and intensity of heat waves, and by warmer summers and milder winter seasons. With this current trend, the average global temperature increase is estimated to go up by 1.8-4.0 ^{0}C by the next century (Bates et al., 2008). The Intergovernmental Panel on Climate Change (IPCC) confirms that climate change has already taken place (IPCC, 2007) and it also assesses future changes in the climate at the regional scale. Massive urbanization, industrialization, aforestation are the prime reasons of such climate change. It represents a range of environmental hazards and will affect populations where the current burden of climate-sensitive disease is high – such as the urban poor in low and middle-income countries (Kovats and Akhtar, 2008). Therefore, adapting to climate change in low and middle income countries is now additional concern for local governments (Satterthwaite et al., 2007).

Especially in developing countries like India, wherein tropical climate, population growth and industrialization are aggravating the scenario. It is observed that globalization and rapid industrial growth in India accounted for 6% of the annual economic growth in the last few years. Substantiating this growth, as per the census 2011, there are

Table 1. Classification of hazardous factories in India as per the factories (Amendment) Act, 1987

Industry
• Ferrous Metallurgical Industries • Non-ferrous metallurgical Industries • Foundries (ferrous and non-ferrous) • Coal (including coke) industries • Power Generating Industries • Pulp and paper (including paper products) industries • Fertiliser Industries • Cement Industries • Petroleum Industries • Petro-chemical Industries • Drugs and Pharmaceutical Industries • Fermentation Industries (Distilleries and Breweries) • Rubber (Synthetic) Industries • Paints and Pigment Industries • Leather Tanning Industries • Electro-plating Industries • Chemical Industries • Insecticides, Fungicides, Herbicides, other Pesticides Industries • Synthetic Resin and plastics • Man-made Fibre (Cellulosic and non-cellulosic) Industry • Manufacture and repair of electrical accumulators • Glass and Ceramics • Grinding or glaxing of metals • Manufacture, handling, processing of asbestos and products • Extraction of oils and fats from vegetable and animal sources • Manufacture, handling, use of benzene/substances containing benzene • Manufacturing processes, operations involving carbon disulphide • Dyes and Dyestuff including their intermediates • Highly flammable liquids and gases
Source: DGFASLI (http://dgfasli.nic.in/html/factyact/csch1.htm)

circa 482 million active workforce in the country. However, this population is unevenly distributed in various occupations accounting less than 1/10th in the organized sector. Alone in agriculture and ancillary activities, around 250 million work as farmers, cultivators and farm labourers work to earn their livelihood. It is noteworthy that the informal sector in India is comprised of those working in the unorganized enterprises or households, excluding regular workers with social security benefits and the workers in formal sector without any employment/social security benefits provided by the employers (NCEUS, 2009).

According to the Annual survey of Industries 2010-11, there are around 2 lakh factories in operation. In addition, there are number of small sized factories that run either with non-registration or de-registered or sometime not submitted their annual returns. The Directorate General Factories Advice Services and Labour Institutes (DGFASLI) states that around 25000 hazardous factories are registered under it employing nearly 13 million workers. The classification of hazardous factories in India as per the factories (Amendment) Act, 1987 is as follows (DGFASLI, 2010).

Almost all of the industries during its manufacturing process generates heat. This heat generation transmits to the environment to make it hotter, as well as to the community, especially affecting the workers involved in the operation. In addition, various other occupational settings are recognized to possess the risk of heat exposure to the workers viz. mining, military, firefighting, agriculture, traffic personnel, sports, construction, cooks, welders, hawkers, shopkeepers, public health personnel etc.

Exposure to Hazard of Heat

Against this backdrop, it is clear that work happens to be in both outdoor as well as indoor settings. The conditions of environment are different in both the setting making it easily comparable. Working in the outdoor environment under natural climates involves the direct exposure to sun, radiant heat, humidity as well as the wind speed. Occupations like agriculture, traffic personnel, construction etc. are under serious threat of such environmental adversities for a considerable duration in a day; the fact that the above-mentioned works are labour intensive demanding a lot of energy. Draining of the body water reserve and musculoskeletal discomfort and disorders are the primary outcomes of working in such environment leading to three kinds of major heat-related disorders - heat cramps, heat exhaustion and heat stroke (Lugo-Amador et al., 2004; Kjellstrom, 2000; Kjellstrom, et al., 2009), in addition to ultraviolet radiation from the sunlight. Particularly in tropical countries like India, a big part of the year becomes very unsafe to work at outdoors resulting in a loss of productivity or an increase in health effects or both.

Besides naturally occurring outdoor hot climates in different geographical regions, indoor workplaces such as industrial settings, manufacturing units are artificial hot atmospheres which often exceeds the climatic stresses found in the natural climates. Industrial establishments with boilers, furnaces heaters directly generate extreme heat which gets transpired among the workers affecting their health. In addition, covered workplaces, poorly ventilated spaces like top floor apartments, building materials with high thermal mass such as brick, lack of or closed windows also play substantive role in heat stress.

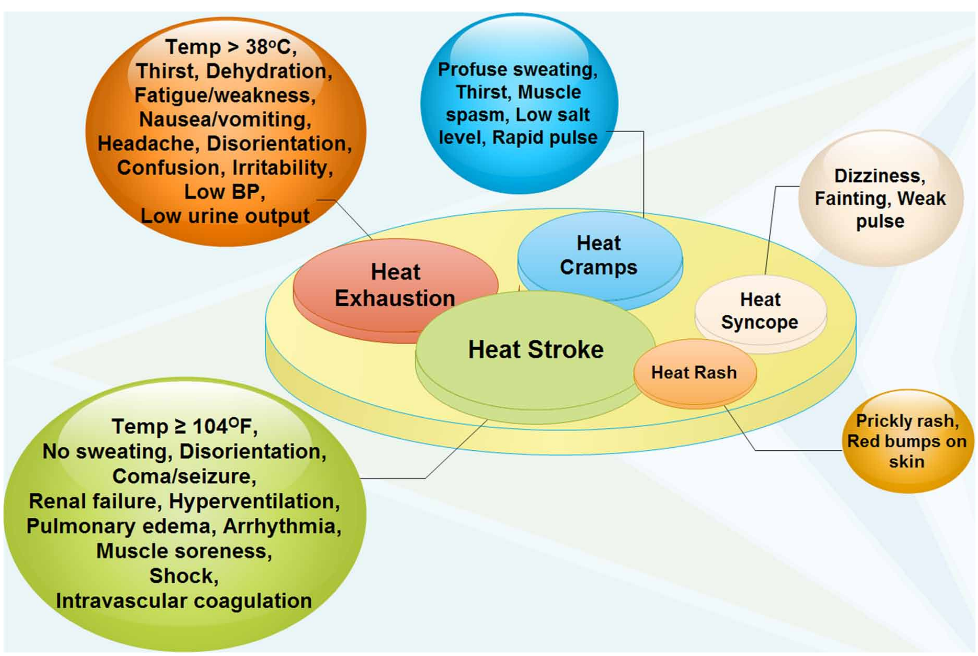
Other community factors that might increase heat exposure are lack of green space and the urban heat island (UHI) effect. In urban areas as well as industrial areas, with express development of buildings, roads, dense concentrations of impervious building materials and surfaces that trap more heat during the day and release heat more slowly at night than natural soil, the temperature increase is likely to proceed faster and to higher levels, known as UHI effect.

Physiological Responses to Hot Environment

Heat generation during production process in industries is a common phenomenon and it is impractical to curb the heat load. However, workers exposed to such arduous environment for long duration are under severe physical as well as psychological stress. When heat is combined with other stresses such as hard physical work, loss of fluids, fatigue or some pre-existing medical conditions, it may lead to heat-related illness, disability and even death (Figure 1).

A working person creates heat internally in the body, particularly through muscular work,

Figure 1. Schematic diagram of heat related illness and associated symptoms (Source: Jackson and Rosenberg, 2010; ACGIH, 2009)



which adds to the heat stress in hot environment (Bridger, 2003). Although with continuous working in such hot environment, there is a marked improvement in the physiologic responses of workers. This improved tolerance to working in heat is known as heat acclimatization. It is said that the primary benefit of heat acclimatization is improved tolerance of heat, evident as a reduction in symptoms of heat illness, and increased work output concurrent with reduced cardiovascular, thermal, and metabolic strain (Armstrong, 1998). However, strategic acclimatization to heat does not occur in case of the workers due to variability of load of work as well as variance in workplace temperature. This calls for attention that acclimatization may be specific to the level of heat exposure to which a worker is exposed, however may not respond well above the levels of exposures (Nag and Nag, 2009).

Moving above acclimatization to heat, some heat related illnesses prop up in condition of excess exposure to hot environment are described below:

- **Dehydration:** Physical workload under hot environment increases the core temperature. Body's cooling mechanism releases a significant amount of fluids to release the excess heat generated and maintain cellular homeostasis. The body thus is at high risk of low water profile, a condition known as dehydration. The body cools itself most efficiently by sweating and having that sweat evaporate. Should sweating be unable to meet the cooling demands of the body, heat-related illness can occur.

Heat stress may cause mild discomfort to even death. Sets of symptoms caused by excess heat and body's autonomic dissipation mechanisms are commonly characterized as one of five illness: heat rash, heat syncope, heat cramps, heat exhaustion, and heat stroke.

- **Heat Rashes or Prickly Heat:** Rashes are a common problems resulting from persistent wetting of clothing due to sweat, and hence blocking of the sweat pores. The condition may be treated or prevented by wearing clean, loose-fitted and lightweight clothing. This forces towards itching and hence may result is rupture of the sweat ducts. In aggravated cases, secondary infections due to deeper rupture of sweat glands may occur.
- **Heat Cramps:** It is characterized by painful muscle spasms, especially in the voluntary muscle of calves, thighs and shoulder and which occurs as a result of hard physical labour in a hot environment, often resulting from an imbalance of electrolytes in the body (Lugo-Amador et al., 2004). Heat cramps occur from salt imbalance resulting from failure to replace salt lost from heavy sweating (ACGIH, 2011). Lower extremity and shoulder muscle groups are commonly affected. These symptoms are the result of electrolyte deficiencies at a cellular level. Hyponatremia and other electrolyte abnormalities may represent an absolute deficiency, or in part a relative deficiency created by fluid replacement with hypotonic solution (Knochel and Reed, 1994).
- **Heat Syncope:** It is a condition of fainting due to body water volume depletion, peripheral vasodilatation, and decreased vasomotor tone and occurs most commonly in elderly and non-acclimatized individuals (Lugo-Amador et al., 2004).
- **Heat Exhaustion**: It occurs both as water and sodium depleted types, with associated symptoms such as vomiting and confusion. Heat exhaustion is a result of the combination of excessive heat and dehydration, heavy sweating, cool moist skin, body temperature over $\geq 100^0$F. Fluid loss

and inadequate salt and water intake causes a person's body's cooling system to start to break down. Treatment involves taking the affected person to a cool environment and replacing fluids and electrolytes. If untreated, heat exhaustion can lead to a heat stroke. Heat related illness that begin with heat cramps, progress to heat exhaustion and finally to heat stroke (Gomez, 2014).

- **Heat Stroke:** Heat stroke is the most serious disorder associated with heat stress. It occurs when the core body temperature exceeds 40^0C (104^0F). The worker may experience cardiac arrhythmias, rhabdomyolysis, serum chemistry abnormalities, disseminated intravascular coagulation, and death. Heat stroke is a medical emergency and should be treated immediately with temperature lowering techniques such as immersion in an ice bath or evaporative cooling.

There are two types of heat stroke - Classic heat stroke may occur in older adults and in persons with chronic illnesses exposed to excessive heat. When the body has used up its water and salt reserves, it stops sweating causing a rise in body temperature. Exertional heat stroke (EHS) generally occurs in young person engaged in strenuous physical activity for a prolonged period of time in a hot environment and the body's cooling mechanism cannot get rid of the excessive heat. Classic non-exertional heatstroke (NEHS) more commonly affects sedentary elderly individuals, persons who are chronically ill and very young persons. Classic NEHS occurs during environmental heat waves and is more common in areas that have not experienced a heat wave in many years. Both types of heat stroke are associated with a high morbidity and mortality, especially when therapeutic intervention is delayed. In India, heat stroke occurs frequently in areas of Northern and Western India, and sporadic cases of EHS are reported in military recruits (Mehta and Jaswal, 2003).

Infants, elderly, athletes, and outdoor workers are the groups at the greatest risk for heat stroke (Atha, 2013). Heat exhaustion and heat stroke may be of particular importance for the occupational health of working people (Kjellstrom, 2000; Kjellstrom, et al., 2009). Cellular metabolism increases 13% for each 1ºC rise in body temperature until the body reaches heatstroke (Gaffin and Moran, 2001). It can also occur when the temperature is not very hot. This is because exertion induced heat stroke can occur when the rate of heat production exceeds the rate of heat loss.

Health Research on Heat Stress

Heat-related morbidity and mortality are likely to increase in response to climate change in future, especially during work. Workplaces in the tropical countries are hub of occupational heat stress which is apparent for longer duration of the year. This affects those who work under the sun as well as in indoor workplace. Particularly, workplace which involved high manual material handling, extreme environmental heat load, poses invariable threat on the health, safety and productivity. Operations involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, or strenuous physical activities have a high potential for including heat stress in workers engage in hot workplace, such as iron foundries, coal mines, stone quarry workers, steel industries, brick firings, ceramic plants, glass and rubber products factories etc (OSHA, 1999).

Studies have been carried out worldwide on various aspects of health among workers working in hot environmental conditions viz. construction workers, miners, farmers, manufacturing workers, steel workers, load handlers (Koltan, 2009), respiratory symptoms, radiographic abnormalities and functional impairments (Neghab et al., 2009), dust exposure and smoking among tile factory workers (Jaakkola et al., 2011). OSHA (2012) reported exerting high levels of force to handle or move materials; doing the same or similar tasks repetitively; working in awkward postures; maintaining static (i.e., nonmoving) body postures for long periods; coming in contact with sharp edges of raw materials and vibrating tools and work surfaces as common ergonomics-related risk among foundry workers (Figure 2-5). In all research it has been observed that working in hot environment increases the risk of injuries and several illnesses and disorders. Almost all the systems of the human body are affected among workers working in hot environment.

Manual tasks are common in most industrial setting as well as agriculture including, loading and unloading of raw materials, pattern and core making, moulding shops, etc. The volume of load in even/uneven shapes, fixed working posture, time bound repetitive work as well as extreme workplace heat are ought to affect the musculoskeletal system, especially the upper and lower extremities and back. Mohan et al. (2008) revealed job factors and work environment as risk factors among workers. Sharma and Singh (2014) reported that male foundry workers were more prone to pain in neck while female workers were more prone to MSDs in upper back and shoulders. Further, correlation analysis showed significant relationship of dimensions work aspects pain and discomforts. Nag et al. (2009) reported 65% of Indian foundry workers with perception of chronic fatigue associated with majority of these workers suffered some type of injuries. In another study, Nag and Nag (2009) emphasized on vulnerability of heat among persons with cardiovascular, respiratory and/or cerebrovascular diseases. Study on workers in ceramics, iron and stone quarry revealed that exposure of 3/4th of the workers to high heat load (30.1-35.5^{0}C) and 1/10th of them to whooping 38.2-41.6^{0}C wherein, ~2/5th of ceramic workers expressed muscle cramps in both extremities (Nag et al., 2013). In addition, cuts, bruises, burns and respiratory disorders are the most common ailments among the workers.

Figure 2. Workers maneuvering hot iron bars from the furnaces

Figure 3. Worker carrying out welding activity in semi-shaded workplace

Figure 4. Workers maneuvering hot iron bars in the moulds

Figure 5. Workers performing manual material handling in outdoor workplace

Noise is a pervasive problem in almost all the work stations (Narlawar, et al., 2006). In addition to noise, vibrations play a major role in affecting various thresholds distributed upon the range of human hearing frequencies. Singh et al. (2012) reported that >90% of workers engaged in various processes of casting and forging industry showed hearing loss in the noise-sensitive medium and higher frequencies. Casting and forging units were significantly associated with noise-induced hearing loss (NIHL), and hearing loss was particularly high among the workers of forging section. The analyses revealed a higher prevalence of significant hearing loss among the forging workers compared to the workers associated with other activities.

As stated earlier that dermal ailments are a major problem due to heat in workplace. Studies have reported workers involved in core handling were most vulnerable to dermal ailments. More et al. (2011) reported that during physical examination of palm of foundry workers from core shop it was noticed that there were white spots on the palm and particularly on finger tips and claw like flexion. Among the potential risk factors for systemic sclerosis, occupational exposures of silica have received little attention.

Along with physical ailments among the workers, psychological and psycho-social well-being of the workers is also affected. Work stressors such as job specialization, working posture, machinery use, hand tools, long hours of work, poor job autonomy, job feedback, task clarity, lack of training, mental overload, low payment etc. causes musculoskeletal disorders (Nag et al., 2012) in addition to overall physiological and psychological stress and strain. Chronic fatigue due to heavy manual material handling in combination with hot workplace causes mental exhaustion that affects everyday life leading to psychiatric problems such as stress and emotional trauma (Evangard et al., 1999). This results in tension with restlessness, agitation, impatience, hyper-reactivity depression, compulsions, phobias and irritability social and domestic disruption due to induced extroversion.

Although, there are very few recent studies that have reported on the effect of heat stress on mental health, literature reports that reduced work productivity, lost income, and disrupted daily social activity are the outcome of working in such arduous work environment. Magnavita et al. (2011) reported both environmental and psychosocial work factors may impact significantly on the development and exacerbation of MSDs and concluded that to prevent MSDs, a multi-level approach is needed, including environmental measures and interventions directed to both psychosocial and organizational factors. Tawatsupa et al. (2010) identified the relationship between self-reported heat stress and psychological distress (adjusted odds ratios ranging from 1.49 to 1.84) among Thai workers. Studies reported from India also reveal that poor work environment, machinery and tool characteristics resulted in poor health and psychosocial stress and associated with injury occurrence (Vyas et al., 2011). A study among iron and steel industry workers reported increased sickness absenteeism (Manjunatha et al., 2011). Study on firefighters revealed that psychological impacts of an emergency situation increases anxiety level. Elevated anxiety among the firefighters may impact on cognitive performance, resulting in inappropriate decision making increasing the risk of injury (Smith et al., 1997).

Further, one basic issue that has not caught critical attention is the gender effect of heat stress vulnerability at work. Noteworthy that gender differences exist in the prevalence of health ailments due to work as well as psycho-social stresses and ample research has been carried out in India on the women at work. Study on women workers in small scale industries revealed that musculoskeletal disorders were the most common health morbidity (Roy and Dasgupta, 2008; Saha et al., 2010). Study on mining and agriculture workers reported deteriorated physical as well as mental health, although agricultural workers were reported being in a better situation than the mining women (D'Souza et al., 2013). Women workers in fish processing industry were found to have work related morbidity like blanching of hand (Odds Ratio: 2.30). The study also reported that grading and packing activities had a significant impact on injury causation among the women workers (Saha et al., 2006). Study among weavers revealed that gender differences exist in the prevalence of musculoskeletal disorders, perception of work and psycho-social stresses among weavers (Nag et al., 2010). Therefore considering substantial contribution of women at various fronts of work with heat stress vulnerability, specific focus needs to be given on the research to excavate the heat stress vulnerability of the women workers.

FUTURE RESEARCH DIRECTIONS

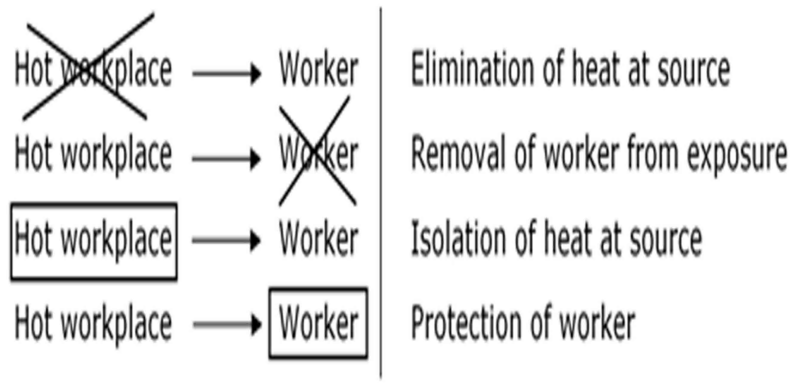
Understanding the quantifiable volume of health impacts due to work habits in hot working environment could provide multiple avenues of suitable intervention. Along with objective assessment of environmental and physiological parameters, human thermal profile; self-reported perception of health issues due to thermal responses plays a pivotal role. This is due to the fact that human perception varies towards health impacts at prevaling environment condition.

The objective assessment of environmental parameters provides crucial information regarding the vulnerability of the workplace. It informs about the prevailing environmental condition which assist in ascertaining the engineering control of the isolation of the worker (Figure 6) as per the already available acceptable working limit norms.

Environmental Microclimate Monitoring

Microclimate is explained as environmental parameters influencing heat exchange between a worker and his/her workplace surrounding. These micro environment climatic factors along with the nature of work performed aid in generation

Figure 6. Modes of controlling heat hazard classified by decreasing order of effectiveness



of a series of biological responses associated with thermal discomforts/comfort. This takes into account the Wet bulb temperature, globe thermometer temperature, ambient temperature, dew point, relative humidity, wind speed. These environmental parameters are used to find out heat exposure indices separately for indoor and outdoor environment known as WBGT index.

WBGT-i (°C) = $0.7t_{nw}+0.3t_g$

(t_{nw}= natural ventilation wet bulb temperature, t_g= globe thermometer temperature)

WBGT-o (°C) = $0.7t_{nw}+0.2t_g+0.1t_a$

(t_{nw}= natural ventilation wet bulb temperature, t_g= globe thermometer temperature, t_a= ambient temperature in shade from direct heat radiation)

BODY TEMPERATURE PROFILING

The body temperature profiling of the exposed workers would provide the scope of necessary intervention into the isolation techniques as mentioned in Figure 2. In this regard the deep body temperature as well as the temperature in the local skin surface gives the complete profile of the affected areas. This can be done by direct temperature measurement using thermometers as an invasive technique. On the contrary infrared thermographic cameras are available as a non-invasive technique and used to capture thermographic images of the local skin. Some cameras allow noting the temperature whereas some store the images digitally for further analysis. The profiling of local skin temperature determines the heat distribution patterns, as well as the work study of the workers and method study of the work being performed by them.

Sweat Loss Profile

While working in extreme hot workplace, sweat loss can exceed 1.5 litres/hour. Literature reports that for each liter of sweat evaporation, 675W of heat are lost (NIOSH, 1986; Nag et al., 2007). However, in certain circumstances, workers experience no sweating and dry skin, which may be due to fatiguing of the sweat glands. In such condition, heat dissipations come to a minimum resulting in various heat related disorders.

Fluid loss in the body is measured by difference in body weight. Worker is asked to wear light clothing termed as weighing clothes. Before start of work, the worker is weighed with weighing clothes on an electronic balance (± 50 g); and then resume to work in normal clothing. Core temperature is recorded from the tympanic membrane (accuracy ± 0.1°C) using thermometer. At the end of the shift, the worker is weighed again in weighing clothes. Fluid and food intake during the shift are weighed and recorded (Miller and Bates, 2007; Bates and Miller, 2008). The difference in body weight is termed as fluid loss.

Health Assessment

The general health checkup through medical examination would assist in understanding the affected system of the body and route forward for specialized investigation. However, prima facie, the socio-economic status of the workers, age, marital status, education, family member dependency as well as approximate income should be recorded. Further addiction to tobacco, smokeless tobacco, etc. as well as details of present and past occupational history must be recorded to acquire the possible relation of heat stress with work. Blood pressure and heart rate are also important factors to understand the cardio-respiratory fitness. In addition, literature reports relation heat exposure with diminished altered pulmonary functions, therefore, standard pulmonary function tests are also advocated on the exposed workers.

Working in industrial settings demand high muscular effort and excessive workplace aggravates the musculoskeletal system to its maximum. Therefore, it is imperative to quantify the muscular strength of the workers in particular work scenario. This can be done by simulating the workplace conditions in a laboratory setting. On the other hand direct measurement of strength can also be done in a fabricated strength measurement set up using suitable load cells (Gite et al., 2009).

It is generally observed that industrial activities generate a huge noise due to its functioning. The workers get exposed to it and contnue working in the same environment for long without any protective intervention. It is also experienced that they get accustomed with the prevailing high intensity noise in their workplace. However, such environment has long term effect on the auditory as well as non-auditory health of the workers. In addition to the effects of various systems of the human body, workers become able to hear only at higher intensities. This also becomes a social stigma. Therefore, the auditory health profile also needs to be monitored at regular intervals for their air conduction and bone conduction audiometry. If required, special audiometric test should also be performed depending upon their job profile.

Self-Reported Work Aspects

The work life in industrial operations as well as outdoor occupations like agriculture etc. are physically strenuous. However, be it acclimatization or the urge to earn, workers continue their work despite understanding the negative side of the workplace environment. Furthermore, perception to work stress, work stressors, health hazards etc. various between individual. Therefore recording of self-perceived work associated heat stress and strain, health complaints, injuries, and pain are equally important to note. Workers may be individually interviewed for assessment of general physical health, including detailed ergonomics work analysis, using a multi-method ergonomics checklist (Nag, 1998). The checklist include enquiry on work systems analysis, such as job characteristics, physical and psychosocial stresses at work, constraints at workplace and tools, hazards of physical environment, etc. The checklist entries were responded by a single digit score, on a five-point common severity agreement/disagreement scale: strong disagreement (1) to strong agreement (5), suggesting that the low score is the positive indicator of the perception of absence of a problem and vice-versa. After summating the response to each question covered under that section and then dividing it by the maximum cumulative score possible in that section, a score was derived for work stressor. The checklist items are described in Table 2.

Table 2. Details of the check points in questionnaire administered

Section	Details of Checkpoint
Job specialization	Specific job, tools and methods, high production volume, quality of work and multiple task
Skill requirement	Training, knowledge, skill required for job, frequent mistakes at work, job rotation and machine paced work
Physical work	Target oriented pace, repetitive movements, muscular exertion and working position
Manual material handling	Handling mode, load weight, distance, height and clothing interference
Task situation	Load handling, material package, handle position, unsafe practices and absence of mechanical aids
Workplace/Workspace design	Work distance away from normal reach, non-adjustable work desk height, poor clearance space, presence of obstacles and cluttered-slippery floors
Seating arrangement	Mismatched dimensions, poor adjustability, absence of vibration damping and absence of hold-support
Auxiliary support	Storage space, restricted passage, design mismatches of staircase, awkward positioning of limbs for hand-foot hold, poor supports and limited gloves/footwear use
Work posture	Arm stretch, wrist extension, neck/shoulder angle, bent and twisted, hips and legs not supported and one sided body movement
Climate	Temperature, ventilation device, absence of regulation and non-availability of drinking water
Lighting	Illumination intense and non-uniform, presence of shadows, flickers and glares, non-adequate color dynamics
Dust	Poor ventilation, absence of protective measures, monitoring chemical toxicants and absence of personal protective measure.
Noise	Noise at work area, absence of sound isolation and emergence measures
Vibration	Transmission by feet, hand-arm and seat, prolonged continuous exposure and possibility to eliminate or isolate.
Work schedule	Working in nights and overtime, uneven distribution of work tasks, incorporation of work rest and working at a predetermined pace limit.
Machinery Control	Awkward positioning, incorrect handedness, mismatched dimension with body parts, force, precision and speed required in operation, absence of shape, color code on it and unpleasant feeling while operation.
Machinery Characteristics	Instability, poor maintenance, speed, handle operation, guarding, warning signal, absence of vibration damping, high noise level and poor visibility of machine.
Tool	Absence of carrying back, cannot be used with alternate hands, heavy weighted, poor handle form and position, sharp edged, non-availability of gloves and high noise.
Machinery safety	Accessories cannot be removed and fastened, poor positioning, contact with body parts lead to injuries, difficult to inspect and lack of instruction for safe operation.
Job autonomy	Time schedules, absence of assistance at work, rigid methods of work.
Job feedback	Non-participation of role for task information, physical barriers, inter person communication difficulty, increased attention demand for machine operation and assessment by others job performance
Task clarity	Unambiguous goal, job restrictiveness, work machine conflict, restricted stimulation, boredom and poor scope
Task Significance	Task planning, job significance and recognition.
Mental overload	Information load, high information handling, high workload, repetitive act, superficial attention, multiple choice and simple motor act
Training	Advancement to higher levels, lack of opportunities, poor training and incentives
Organizational issues	Conflicts of organizational role, absence of medical and administrative services, lack of promotional measures, ineffective safety regulations, absence of inspection and monitoring and absence of follow-ups after accident and injury management

Musculoskeletal Discomforts

Work related Musculoskeletal Disorders (MSDs) might emerge as a major health problem among workers. The musculoskeletal pain and discomfort in different body parts can recorded using OSHA's MSD questionnaire (Cohen et al., 1997). Workers' response in relation to pain, severity of pain, localization of pain in the specific body segment, sickness absence/interference with work, remedial measures adopted by them and their perception about the factors associated to pain can provide a clear picture of the intensity of workplace hazard.

Perception to Workplace Health

To understand the heat associated worklife, perception responses of the workers regarding daily water intake, frequency of urination, sweating, thirst, dehydrated mouth, muscle pain/spasm, elevated body temperature gives an opportunity for work study, method study and possible intervention. Likert attitude scale can be used which indicates the responses to "secondary statement" by a single digit score on 5-point, low score is a positive indicator of perception of absence of a problem (Likert, 1932).

Identification of health status indicators in both subjective and objective technique would aid in reducing morbidity or mortality rates and reducing risks of ill health among the Indian workmen, especially those who work in extremely hot workplace. It would be a step forward to comprehend the mutual relationships & interactions of the above factors to yield dimensions of workload, health status and disorders for the betterment of work life of the population involved. Elucidating the multiple avenues of their work pattern, physical and physiological attributes would generate knowledgebase and yield numerically defined susceptibility limits of workers occupational front.

OBSERVATIONS

The primary observations regarding the health effects due to working in the hot environment are notable. Heavy sweating, fatigue/weakness, loss of work capacity, muscle cramps, decreased urine output, excessive thirst, headache, skin problems (itching/irritation/prickly sensation, pink or red bumps), loss of appetite, digestive, respiratory and cardiovascular discomforts are among the responses of the workers during their daily work schedule. In addition, elevated body temperature threshold shift among the workers working in hot environment instigates various physiological functions. Continuous exposure to heat and heavy sweating also set off the tendency towards being hypertensive.

Work related musculoskeletal disorders have been reported in many occupations e.g. upper extremities and low back pain are one of the leading causes of lost workday injury and illness. Workers engaged in various heavy workload tasks are often exposed to ergonomic-related injury risks, such as lifting heavy items, bending, reaching overhead, pushing and pulling heavy load, working in awkward body postures and performing the same or similar tasks repetitively (OSHA, 2012).

The psychological effects are also a prime outcome of workload in this extreme hot environment. Loss of concentration/mental overload, job autonomy, work schedule, work shift, work noise and communication constraints, auxiliary supports, precision, timely task accomplishment, time limits, trainings, accidental follow ups and injury management, job satisfaction impact the physiological as well as psychological well-being of the workers. Along with objective measurement of the health effects, self-reported perceived responses provides a basis towards designing intervention techniques (D'Souza et al., 2013). Although, self-reported estimates have the limitations of recall bias, it is a measure of prevailing condition as well as the health outcome prevalence.

Case Study

An observational visit was made in an iron foundry to assess the environmental scenario as well as workers perception to the workplace and health aspects. The workplace environment was monitored and workers were interviewed for their self-reported work aspects, perception to workplace health and heat stress. The environmental monitoring revealed that workplace in an iron foundry is extremely hot particularly in and around the furnace area (ambient temperature: 43.4±3.7^{0}C). It was observed that the temperature rises as the day progresses and even reaches above 50^{0}C. The workers also revealed that the post-lunch session is the most difficult phase of work in these types of industries.

It was observed that primarily the engaged work force was young and work for around 10-12 hours a day. The average tenure of the workers in these industries was around 4 years which was attributed to these difficult working environments. These workers reported of various health ailments due to working in such environment, long working hours, heavy physical load and maintaining working pace with the mechanical continuity of the work process of production (Figure 7).

Further on analysis of their responses to the multi-method ergonomic review technique questionnaire, it was noted that continuous physical workload, manual material handling, extreme workplace heat, mental overload, low wages were the prime factors affecting their health and continual engagement in these industries (Figure 8).

Workplace heat health perception of the workers revealed that heavy sweating and excessive thirst were the most common problems faced by the workers (Figure 9). However due to the continuous work pace in the mechanized process of production, the thirst is perpetually compromised. This may be the reason of heat related disorders among the workers. Musculoskeletal disorders, fatigue are the prominent responses among the workers, in addition to mental disorientation and gastrointestinal disorders.

Inevitably the workplace in such industries is a difficult one, although the workers continue to work in such environment for livelihood sustaining. Work-rest cycles, personal protective equipment, job rotation, adherence to working hours limit, automation in heavy and frequent material handling and periodic health checkup would be the instruments in protecting their life and increase the productivity.

CONCLUSION

Working in hot environment in tropical Indian climate is a climatic threat on human health and well-being posing risk on the economic and social costs as well as adaptive capacities of the humans. Extreme heat events are becoming frequent across

Figure 7. Self-reported systemic health complaints among the workers

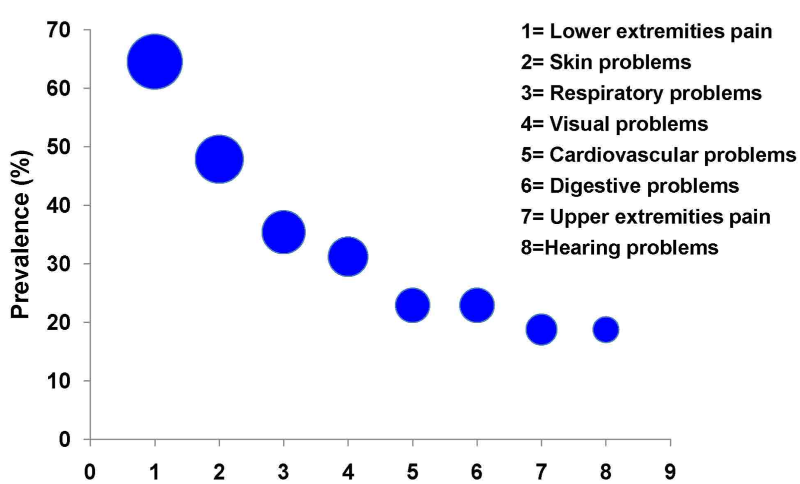


Figure 8. Relative loading of work stressors in the workplace

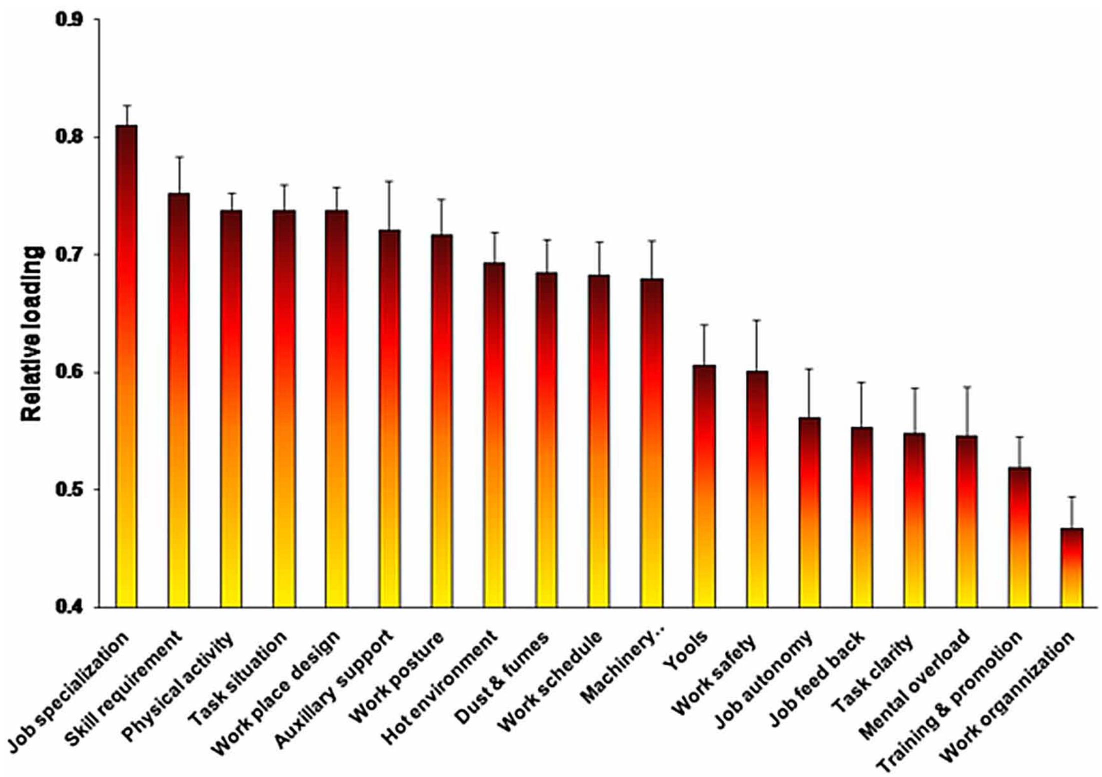
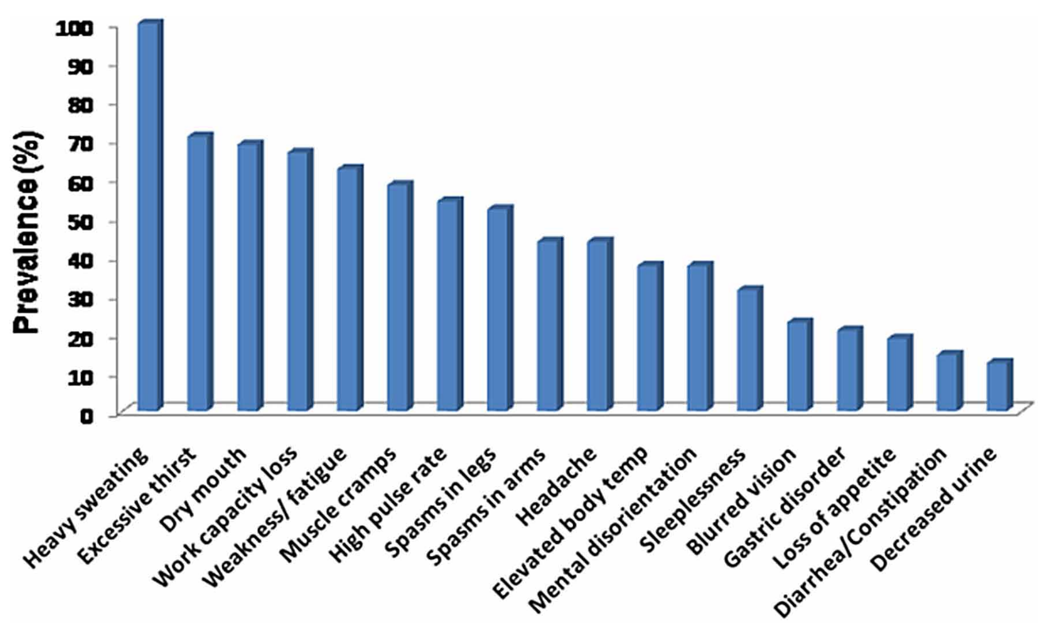


Figure 9. Self-reported responses to heat related disorders among the workers



India particularly with the growth of industrialization. The workers in industrial establishments along with the people in the community get affected to various heat related mortality and morbidity. Occupational heat exposure not only results in heat illnesses, but also productivity is affected. Myth exist that workers get habituated to such environment and continue their work for years. However, with continuous exposure to such hot environment accompanied by strenuous workload and time bound activities, physiological as well as psychological challenges become inevitable. Lack of awareness, training, facilities to combat the potential threats to excessive heat exposure increases the risk of heat related injuries. The present chapter attempted to provide directions to research into the heat related health profile of the Indian workmen which would ascertain the relative vulnerability of different occupational groups to their workplace heat eventuality.

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Section 2
Vulnerability

Chapter 5
Vulnerability to Climate Change:
Issues and Challenges towards Developing Vulnerability Indicator

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ABSTRACT

This paper is based on a detail review of literature available in the area of climate change, vulnerability and impact assessment. Methodological issues pertaining to vulnerability like; development of vulnerability indicators, process of indicator selection etc are the main focus in this paper. As discussed indicators are more acceptable, easy to understand and help in comparing across regions. However, indicators also possess a number of limitations. There are issues in selecting indicators and how to aggregate their values. The current study tries to overcome those issues through a primary study. The study region is Mumbai, India and 'Koli' fishing communities reside in the city. The socio-economic implications of climate change and vulnerability of communities depending on fishery are estimated by developing vulnerability indicators using Sustainable Livelihood Approach (SLA), and Analytic Hierarchy Process (AHP). Further experts opinions are considered while selecting indicators. Vulnerability indicators are derived from literature and validated through experts' opinion. Experts are chosen from higher learning institutes in the city. In the climate change literature vulnerability mainly divided into exposure, sensitivity and adaptive capacity. The indicators of sensitivity and exposure under vulnerability are combined here and categorized into two: livelihood and perceived changes. Similarly the indicators of adaptive capacity are of five categories comprising human, physical, financial, social and government policy related indicators. Thus a total 30 indicators are selected. Among five fishing villages surveyed, fishermen from Madh and Worli are found more vulnerable because of their high sensitivity and low adaptive capacity. The derived vulnerability scores are further compared and analyzed against the scores derived from experts. The overall result shows the experts value of indicators are similar with the indicator score derived in the study using simple aggregate method. This study further provides policy implications for reducing vulnerability of fishing villages.

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1. INTRODUCTION

"Vulnerability" describes the degree or state of susceptibility or capacity to which a system is likely to experience harm due to the occurrence of a physical or natural event (Fussel, 2007). Vulnerability is used in two different connotations: a negative definition (e.g. risk, sensitivity and fragility) and a positive definition (e.g. resilience, adaptability, adaptive capacity and stability) (Brikmann, 2006). Vulnerability assessment studies are increasing not only in the field of climate change impact assessment and adaptation but also in the areas of hazard impact analysis, food insecurity, poverty and development economics.

However, the interdisciplinary nature of vulnerability often creates conceptual and methodological challenges. Vulnerability is not defined properly (Hinkel, 2008) and it has a variety of meanings and used differently within the climate change community (Brooks, 2005; Ionescu et al., 2005) as well as in other related disciplines (Senapati and Gupta, 2012). The methodologies for vulnerability assessments can be distinguished into "top-down" approaches and "bottom-up" approaches (Dessai et al., 2004; Fussel and Klein, 2006; Hinkel, 2008). The top-down methodologies have their roots in the fields of climate change and climate impact assessment. The focus lies more on the biophysical aspects of vulnerability. The methodologies for the same consist of developing climate scenarios, which are then fed into models of biophysical systems followed by a socioeconomic impact and adaptation assessment (IPCC, 1995; Feenstra et al., 1998). The "bottom-up" vulnerability assessment approach on the other hand focuses on the social aspects of vulnerability of individuals and communities to climate change and climate variability. The bottom-up methodologies have their roots in the fields of natural hazards, food security and poverty. This approach also analyses past experiences of how communities have coped with extreme events as a guide to future thresholds and adaptive behaviour. Generally, the methodologies for bottom-up approaches consist of conducting case studies at the level of local communities social conditions, institutions and the perception of vulnerability are thereby emphasized.

The vulnerability studies based on ranking and comparing across regions, countries, and populations have increased in number during the past decade. The main objective of these kinds of studies is the allocation of resources for vulnerability reduction by including decision making authorities like government bodies and other organizations. Indicators are especially developed in order to compare two regions (for example Human Development Index), however indicators have limited usage. Several studies have been attempted in developing national level indicators to describe vulnerability of social-human system, these studies dealt with various hazards and geographical regions (Moss et al., 2001; Adger et al., 2004). However, the construction of these indicators involves many uncertainties in finding appropriate scale, and appropriate criteria for aggregating indicators. For example, at national level the indicator of adaptive capacity depends on financial capacity and institutional capacity of a country for making resources available for the most vulnerable areas and people. Whereas at household level, the adaptive capacity of a person depends on his/her knowledge, perception towards climate change, and financial capability that helps in identifying new or modified livelihood opportunities and access to resources for achieving that level of adaptive capacity (Vincent, 2007).

Many of the vulnerability indicators developed so far are based on a data driven or inductive approach. The common methodologies used for this are factor analysis, principal component analysis, expert judgment, and correlation analysis. On the other hand, a theory-driven approach uses theoretical insights into the nature and causes of vulnerability for deriving the indicators. Hahn et al. (2009) used a deductive approach for selecting vulnerability indicators for Mozambique and developed a 'livelihood vulnerability index'. The indicator selection method for this study is based on the literature survey related to the Sustainable Livelihood Approach (SLA) (Haidar, 2009). They also used primary data at household level. However, these local level theories only provide arguments for the selection and not for the aggregation of indicating variables. Ekin and Tapia (2008) used multi-criteria analysis to assign weights to indicators along with livelihood approach for measuring vulnerability for agricultural household of Tamaulipas, Mexico. Despite the weaknesses and difficult methodological choices in deriving vulnerability indicators, there is a need to quantify social vulnerability, especially at household and community levels.

This paper is based on a detail review of literature available in the area of climate change, vulnerability and impact assessment. The literatures on vulnerability are multidisciplinary comprising broad areas of economics, sociology, geography, disaster management etc. IPCC reports on climate change vulnerability are given priority while conducting the review. Methodological issues pertaining to vulnerability like; development of vulnerability indicators, process of indicator selection etc are the main focus in this paper. As discussed indicators are more acceptable, easy to understand and help in comparing across reasons. However, indicators also possess a number of limitations. There is a paradigm shift from top-down studies to bottom-up studies in the area of climate change impact and vulnerability assessment. Bottom-up studies are more localized and region specific studies. Although climate change is a global problem and initially researchers focused on mitigating climate change, but the need of the hour is adaptation and providing localized solutions for which a detailed discussion on the techniques to measure vulnerability and the extent of vulnerability is needed.

The paper consists of seven important sections. Section 2 discusses the process of indicator development. Section 3 of this paper is literature review on vulnerability and indicators of vulnerability. Studies pertaining to vulnerability in India are also discussed in this particular section. In section 4 an alternative method of indicator development is presented. The indicator selected for the current study as well as the process of allocating weights to these indicators are discussed in detail. Section 5 analyses the process of converting primary data collected to indicator score. Section 6 discusses and analyse the results. Section 7 is the conclusion.

2. PROCESS OF INDICATOR DEVELOPMENT

The initial step in indicator development is defining what to be indicated. In the context of climate change vulnerability assessment, it is the vulnerability of an entity to climate change that needs to be defined. Various entities such as individuals, households, communities, ecosystems, regions, economic sectors and countries could be considered. The second and most important step is the selection of the indicating variables and there are a few selection criteria for this like; relevance of the selected indicators/proxy for the purpose, accuracy of the indicator values, timelines in the collection of data for the indicators, accessibility of the data from the original sources, interpretability of the indicators should be simple and easy to understand, and coherence and logical reflection of the indicator selected for the study (OECD, 2008).

3. LITERATURE REVIEW

The following table (Table 1) summarizes some of the important literature in the area of vulnerability and adaptive capacity. The table provides information in which region/country these studies have been conducted and whether primary or secondary data are used. The detail discussions of these studies are also provided in the following.

Table 1. Indicators of vulnerability and adaptive capacity

Source	Vulnerability/ Adaptive Capacity	Country/ Type of Data	Context	Indicators
Adger, 1999	Social Vulnerability	Vietnam (Both Primary and Secondary data)	Poverty	Income
			Resource dependency	Migration, health
			Inequality	Access to economic assets, infrastructure
				Institutional arrangements, Perception of institutional change
Adger et al., 2004	Vulnerability (Based on only Secondary data)	General (National level indicators)	Economic wellbeing	National wealth, inequality, economic autonomy
			Health and nutrition	State support for health, Burden of ill health, Health care availability, nutritional status, access to nutrition
			Education	Educational commitment, Entitlement to information
			Physical Infrastructure	Isolation of rural communities, quality of basic infrastructure
			Governance related factors	Effectiveness of policies, willingness to invest in adaptation
			Demographic and geographical	Coastal risk, infrastructure, diseases
			Agriculture	Dependence on agriculture
			Natural resources and ecosystem	Environmental status
			Technical capacity	Capacity to undertake research and commitment
Cutter et al., 2003	Social Vulnerability	U.S.A (Based on Secondary data)	Personal Wealth	Per-capita income
			Age	Median age
			Density of the Built environment	No. of commercial establishment
			Economic dependence	Employment
			Housing stock	Mobile homes
			Race	Migration
			Ethnicity	
			Occupation	Employment in Service occupations
			Infrastructure dependence	Employment in transportation, communication etc.
O'Brien et al., 2004b	Vulnerability to climate change and globalization (Secondary data)	India	Biophysical	Soil condition and ground water availability
			Socio-economic	Levels of human and social capital, presence/lack of alternative economic activities
			Technological	Availability of irrigation and quality of infrastructure

continued on following page

Table 1. Continued

Source	Vulnerability/ Adaptive Capacity	Country/ Type of Data	Context	Indicators
Moss et al, 2001; Brenkert and Malone 2005	Vulnerability to climate change	India (Secondary data)	Economic capacity	GDP (market)/capita, Gini index
			Human and civic resources	Dependency ratio, literacy
			Environmental capacity	Population density, So2/area, % land unmanaged
			Settlement infrastructure	Population at flood risk from SLR, Population without access to clean water and sanitation
			Food	Cereals production/area, animal protein consumption/ capita
			Ecosystem	% land managed, fertilizer use
			Human health	Completed fertility, life expectancy
			Water resources	Renewable supply and inflow, Water use
Smith and Wandel, 2006	Vulnerability	General (Community level)	Exposure/Sensitivity	Settlement location and types
				Livelihoods
				Land use
			Adaptive capacity	Context specific varies among countries, communities, Individual and groups
Deressa et al., 2008	Vulnerability	Ethiopia (Secondary data)	Adaptive capacity	Wealth (livestock, radio, non-agricultural income, etc.)
				Technology (Fertilizer used, etc)
				Infrastructure and institutions (Roads, telephone services, food market etc.)
				Irrigation potential
				Literacy rate
			Sensitivity	Extreme climate (frequency of droughts and floods)
			Exposure	Change in climate (Change in temperature, precipitation)
Eakin and Tapia, 2008	Vulnerability	Mexico (Based on Primary data)	Adaptive capacity	Human resources (Age, education etc.)
				Physical resources (land area, irrigation, tractor etc.)
				Financial resources (credit, insurance etc)
				Information (climate information, technical)
				Diversity (income)
			Sensitivity	Livelihood (Migrants, income)
				Crop (type of crop, climate change etc)
Hahn et al., 2009	Livelihood vulnerability	Mozambique (Based on Primary data)	Socio-demographic	Dependency ratio, percentage of female headed households etc.
			Livelihood strategies	Percentage of households working in a different community etc.
			Social networks	Borrowings etc.
			Health	Health facility, percentage of households having chronic illnesses etc.
			Food	Percentage of households dependent solely on family farm for food etc.
			Water	Percentage of households reporting water conflict etc.
			Natural disasters and climate variability	Average number of cyclones, floods, drought events in the past 6 years etc.

Adger (1999) has measured social vulnerability to climate change and climate extreme for coastal Vietnam. Social vulnerability is divided into individual and collective vulnerability. Individual vulnerability is determined by access to resources and the diversity of income sources, as well as by social status of individuals or households within a community. Whereas collective vulnerability of a nation, region or community is determined by institutional and market structures, such as the prevalence of informal and formal social security and insurance, and by infrastructure and income. The major indicators of vulnerability are poverty, and resource dependency at individual level Inequality and institutional adaptation at collective level. Various proxy variables are used to estimate these indicators, for example-data on income is used as proxy for poverty, the resource dependency are measured through agricultural activities and other coastal activities like salt making. Both Secondary and primary data are collected from Xuan Thuy district of northern Vietnam during 1995 and 1996. The primary data is collected through a household survey and semi-structured interview among the key informants of 11 communities based on a stratified area sample. Secondary data are also collected on Xuan Thuy district for agricultural production, income, population and other variables and on 80 coastal aquaculture enterprises. To measure institutional adaptation and of institutional inertia in the treatment of present climate extremes in Xuan Thuy district qualitative data are collected from community level officials and from households within these communities, as well as discussions at the district level. The study found institutional adaptation has a major influence in deciding the vulnerability In case of Xuan Thuy District.

In another study by Tyndall Centre for Climate Change Research, UK (published by Brooks, 2003; Adger et al., 2004; Brooks et al., 2005; Haddad, 2005) national level indicators of vulnerability and adaptive capacity are developed. They have constructed a conceptual framework for vulnerability in which risk (or disaster) is viewed in terms of outcome, and is a function of physically defined climate hazards and socially constructed vulnerability. They have collected a large set of data for different countries around the world and analysed two different categories of vulnerability (specific vulnerability also called bio-physical vulnerability or outcome risk and the generic vulnerability). Specific vulnerability is represented in terms of mortality outcomes from climate-related disasters using data set from the emergency events database (EM-DAT). They have identified 46 variables for generic vulnerability, representing economic well-being and inequality, health and nutritional status, education, physical infrastructure, governance, geographic and demographic factors, agriculture, ecosystems and technological capacity (see table in appendix). Proxy data representing each variable for generic vulnerability are acquired from a variety of international data sources, subsequently a composite vulnerable index is developed (Similar to HDI) by assigning equal weights to each indicator, the method of aggregation is analysed in details by Anand and Sen, 1994, Downing and Patwardhan, 2003; Kumar and Tholkappian, 2006. The results of the above study indicate that the most vulnerable nations are those situated in sub-Saharan Africa and those have recently experienced conflict like: Iraq and Afghanistan.

Cutter et al. (2003) have constructed a social vulnerability index (SoVI) to environmental hazards for the U.S.A based on 1990 level data. There are a number of factors that influence social vulnerability some of them include: lack of access to resources (information, knowledge and technology), limited access to political power and representation, social capital (social networks, beliefs, customs, etc.). Based on literature and availability of data they have identified a number of factors (250 variables) for measuring the above indicators. After testing multi co-linearity among the variables, total 85 variables are selected. Again they have used a factor analysis method to derive the independent and dependent variables, a set of 11 factors were produced. Based on the factor scores, they derived the composite social vulnerability index score for 3,141states in the U.S.A. The SoVI score ranges from –9.6 (low social vulnerability) to 49.51 (high social vulnerability) with mean vulnerability score of 1.54 (SD=3.38) for all U.S.A states. The result implies a vast majority of U.S.A states exhibit moderate levels of social vulnerability and the most vulnerable states are the southern half of the nation, stretching from south Florida to California (the regions with greater ethnic and racial inequalities as well as rapid population growth).

O'Brien et al. (2004) have developed and examined a methodology for vulnerability mapping to two stressors (climate change and economic globalization) by applying it to India's agriculture sector. The method involves four steps (i) developing a national vulnerability profile for climate change at the district level, (ii) developing a national vulnerability profile for an additional stressor at the district level, (iii) superimposing the profiles to identify districts in India that are 'double exposed', and (iv) conducting case studies in selected districts. Various factors (biophysical, socio-economic and technological) affecting the capacity to adapt are derived. The biophysical factors include soil quality and depth, and groundwater availability, whereas socio- economic factors are the measures of literacy, gender equity, and the percentage of farmers and agricultural wage laborers in a district. Technological factors comprise the availability of irrigation and the quality of infrastructure. Together, these factors provide an indication of which districts are most and least able to adapt to drier conditions and variability in the Indian monsoons, as well as to respond to import competition resulting from liberalized agricultural trade. The results of this vulnerability mapping show that the districts located along the Indo- Gangetic plains (except Bihar) are having higher degrees of adaptive capacity and lower adaptive capacity in the interior portions of the country, particularly in the states of Bihar, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, and Karnataka. Further a climate sensitivity index (CSI) is derived for the period 1962-1990 and it is found that the areas with high to very high climate sensitivity for agriculture are located in the semiarid regions of the country, including major parts of the states of Rajasthan, Gujarat, Punjab, Haryana, Madhya Pradesh, and Uttar Pradesh.

In the next step vulnerable districts to economic globalization (i.e., liberalization of agricultural trade) are identified by combining the values of the adaptive capacity for each district and import sensitivity indices. The results show high vulnerability in most of districts of Rajasthan and Karnataka, as well as in substantial portions of Bihar, Madhya Pradesh, Maharashtra, Gujarat, and Assam. Most of the districts concentrated in Rajasthan, Gujarat, Madhya Pradesh, as well as in southern Bihar and western Maharashtra, are identified as „double exposure" areas, where globalization and climate change are likely to pose simultaneous challenges to the agricultural sector.

However, the indicators derived here for mapping vulnerable profile are at macro levels and does not include policies, local institutions, and other types of interventions and initiatives that may have a notable influence on vulnerability. To understand the role of these factors, in the next step the study has analyzed local-level case studies in villages located in highly vulnerable and less vulnerable districts. The case studies carried out in 2002–2003, employed a variety of participatory rural appraisal techniques like interview with government officials, discussions with local experts from governmental and non-governmental organizations. Finally, household surveys are carried out in Jhalawar district of Rajasthan, Anantapur district of Andhra Pradesh, and Chitradurga district of Karnataka. The results of these case studies support the macro- profiles, which indicated that climate vulnerability will overlap with vulnerability to economic changes.

And it is also found that institutional barriers or support systems have an important role on local-level vulnerability.

Moss et al. (2000) have developed a vulnerability- resilience indicator prototype (VRIP) model and according to the model a country's or region's vulnerability to climate change is assumed to be a function of three factors, exposure, sensitivity and adaptive capacity. The estimation of a society's coping and adaptation capacity is based on society's human resources, economic capacity and natural capital. Sensitivity of a society to climate variability and change is based on an evaluation of its food and water security, its settlement security, aspects of the health of people, and natural resources.

Based on VRIP model, they have calculated indicator scores for both current and potential future conditions for 38 countries and the world using 1990 national level data. Out of 38 countries 16 countries (Mexico, Saudi Arabia, Uzbekistan, Sudan, Ukraine, Nigeria, Thailand, Libya, South Africa, Senegal, Bangladesh, Egypt, China, Tunisia, India, and Yemen) are considered more vulnerable to climate change impact than the world as a whole. Considering three different future climate scenarios, the study found by the year 2095 only one country remains vulnerable in the rapid growth scenario (Yemen) three countries (Bangladesh, India, Yemen) are vulnerable in the local sustainability scenario and nine countries (Senegal, South Africa, Egypt, China, Tunisia, Uzbekistan, Ukraine, Bangladesh, India and Yemen) are vulnerable in the delayed development scenario. This particular study has estimated the vulnerability scores for different country and on the basis of vulnerability scores countries are ranked, however the underlying causes of vulnerability are not explored here. In this study India in particular found to be more vulnerable in current level scenario and in two future scenarios.

Brenkert and Malone (2005) have assessed vulnerability of India and Indian states by using the vulnerability-resilience indicator prototype (VRIP) model. The model was initially developed by Moss et al. (2001) and analyzed earlier in this report. The study has collected data for 17 necessary indicators (of exposure, sensitivity and adaptive capacity) from various government and non-government sources between 1990 and 1998. The overall results show six states (Goa, West Bengal, Kerala, Tamil Nadu, Orissa, and Gujarat) are more vulnerable than India as a whole. All the six most vulnerable states are coastal states, with high population densities. Water availability was shown as an important sensitivity sector.

Hahn et al. (2009) have developed the livelihood vulnerable index (LVI) to estimate climate change vulnerability in the Mabote and Moma district of Mozambique. The LVI has practical uses and it helps the development organizations, policy makers, and public health practitioners to understand demographic, social, and health factors contributing to climate vulnerability at the district or community level. For developing LVI they have used primary data from household surveys during 2007. Around 20 villages consists of 200 households are surveyed by selecting seven major components of LVI, socio-demographic profile, livelihood strategies, social networks, health, food, water, and natural disasters and climate variability. The first step of LVI is to develop a composite index (using the methodology of HDI), a weighted average approach where each sub-components contributes equally to the overall index. In the next step an alternative method is used for calculating the LVI that incorporates the three contributing factors to vulnerability, these are exposure, sensitivity, and adaptive capacity (followed from IPCC, 2001b). Exposure here is measured by the number of natural disasters that have occurred in the past 6 years in both the districts, while climate variability is measured by the average standard deviation of the maximum and minimum monthly temperatures and monthly precipitation over a 6-year period. Adaptive capacity is quantified by the demographic profile, the types of livelihood strategies, and the strength of social networks. Sensitivity is measured by assessing the current state of a district's food and water security and health status. Results suggest that Moma may be more vulnerable in terms of water resources and health profile while Mabote may be more vulnerable in terms of socio-demographic structure.

3.1. India Specific Studies

Assessment of the physical impact of a 1-meter SLR for Indian coastal states are done by a number of institutions and these cases studies are synthesized by Jawaharlal Nehru University (JNU) in the year 1993 (Noronha et al., 2003). A country's vulnerable to SLR is the proportion of its population and productive land that is within a few meters of the existing mean sea level. And it is estimated that one meter sea level rise will directly affect 5763 km2 (0.41%) of the combined area of coastal states. The study also found Mumbai as the most vulnerable district where as Ratnagiri (both are from Maharashtra) as the least vulnerable in terms of loss in area and population affected. Further the extent of vulnerability not only depends on the physical exposure but also on the level of economic activity in the region. Noronha (2003) has added another indicator, the district level index of relative development which reflects the levels of income and social and physical infrastructure in the district. And in her ranking of vulnerable coastal district Chennai is found as the highest vulnerable district and Tiruvannamalai (both in Tamil Nadu) emerge as the least vulnerable to a potential 1-metre SLR. The monetary loss of 1- metre sea level rise as estimated by TERI (1996) ranges from Rs. 2,287 billion for Mumbai to Rs. 3.6 billion for Balasore (in odisha) (cf. Gupta, 2005).

In another study Patwardhan et al. (2003) have estimated the impacts and vulnerability of climate change on coastal zones of India. Their study focus on climate related natural hazards in the coastal zone, particular on tropical cyclones. Vulnerability here is considered as a combination of hazard, exposure and adaptive capacity. Exposure here is characterized by various aspects of population (such as population density) and housing stock classified by material of construction. And adaptive capacity is the ability of the exposed unit to perceive, formulate a response and implement response to climate risk, with a view to reducing impacts. On the basis of data on number and frequency of tropical cyclones collected from Indian Meteorological Department (IMD, Pune) for the period 1877 to 1990, a cyclone hazard index was developed and districts are ranked accordingly. Census data are used to estimate the physical and socio economic exposure. Various index like; housing index and population index are developed and districts are ranked. An impact index is also developed on the basis of data on human mortality, livestock mortality, damage to house, damage to crop loss in monetary term and population affected. The data for the same are collected from IMD and CRED (Centre for Research on Epidemiology of Disaster) for the year 1971 to 2001. Overall impacts of climate change and vulnerable districts are derived with the help of cluster analysis. A cluster of highly vulnerable districts include Cuttack, Jagatsinghpur and Kendrapada in Odisha, Nellore in Andha Pradesh, Junagadh and Porbandar in Gujarat, Nagapattinam in Tamil Nadu. The second cluster includes districts those are somewhat vulnerable, North 24 Parganas and South 24 Parganas in West Bengal, Balasore and Bhadrak in Odisha, Guntur, Krisha, East Godavari and Srikakulam in Andhra Pradesh, Ramanathpuram, Cuddalore, Thiruvallur in Tamil Nadu. The number of vulnerable districts in east coast is found to be more in comparison to west coast because the frequency and magnitude of tropical cyclone is more in those districts. Finally the study has also identified some of the important adaptation measures for coastal ecosystem. In this particular study three different types of indicators (relating to exposure, impact and adaptive capacity) are developed instead of developing a single index.

Kumar and Tholkappian (2006) have estimated the relative vulnerability of coastal districts of India by using an integrated vulnerability index, which define as a function of the exposure, sensitivity and adaptive capacity of the districts. The study has also ranked districts in terms of the likely number of human causalities due to potential climate surge associated with cyclonic storms. Like the above study this study has also found the number of vulnerable districts on the east coast is more than west coast. The main purpose of the study is to provide insights on prioritizing adaptation for specifically vulnerable region.

4. VULNERABILITY ASSESSMENT

Vulnerability reduction and sustainable development are two important elements of adaptation to climate change. Adaptation in this context is looked through a wide variety of economic, social, political, and environmental circumstances (Senapati and Gupta, 2012). In this paper household vulnerability indicators are developed with the help of SLA (Badjeck et al., 2010) and Analytic Hierarchy Process (AHP) (Saaty, 1980; Ekin and Tapia, 2008).

4.1. Vulnerability Indicator and Their Development Process

Vulnerability studies frequently considered national level indicators (Moss et al., 2001; Adger et al., 2004). However, the construction of these indicators involves many uncertainties in finding appropriate scale, and appropriate criteria for aggregating indicators. For example, at national level the indicator of adaptive capacity depend on financial and institutional capacity of a country for making resources available for the most vulnerable areas and people. Whereas at household level, the adaptive capacity of a person depends on his/her knowledge, perception towards climate change, and financial capability that helps in identifying new or modified livelihood opportunities and access to resource for achieving that level of adaptive capacity (Vincent, 2007). Many of the vulnerability indicators developed so far are based on a data driven or inductive approach. On the other hand a theory-driven approach uses theoretical insights into the nature and causes of vulnerability for deriving the indicators (Hahn et al., 2009). However, these local level theories only provide arguments for the selection and not for the aggregation of indicating variables. Ekin and Tapia (2008) used multi-criteria analysis to assign weights to indicators along Sustainable Livelihood Approach (SLA) (Scoones, 1996; Hahn et al., 2009) for selecting indicators.

4.2. Multi-Criteria Decision Analysis (MCDA)

Multi-criteria analysis is a type of decision analysis tool that is particularly applicable to cases where a significant environmental and social impact cannot be assigned monetary values. MCDA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria i.e., when multiple options are to be evaluated against multiple criteria (Munda et al., 1994; Alier et al., 1998; UNFCCC, 2008). In MCDA, desirable objectives are specified and corresponding attributes or indicators are identified on the basis of chosen criteria to measure the objectives. The actual measurement of indicators need not be in monetary terms, but is often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. The analytic hierarchy process (AHP) is the most common approaches within multi-criteria analysis (Ananda and Herth, 2009).

4.3. Analytic Hierarchy Process

The AHP model was initially developed by Thomas L. Saaty (Saaty, 1980), that provides a framework to make decisions involving different kinds of concerns such as planning, setting priorities, ranking alternatives, selecting the best among a number of alternatives and allocating resources. The AHP model has been applied in a wide range of areas to analyze preferences for management objectives and alternatives (Ryu et al., 2011). In case of climate change vulnerability assessment, the AHP model can be applied to indicators measurement of individual preferences by weighting and comparing the sub-components with each other (Eakin and Tapia, 2008). AHP has also been widely used in fisheries sector to determine the relative importance of different management objectives (Innes and Pascoe, 2010). The effectiveness of AHP resides in its capacity for decomposing the complexity of the ranking problem into a hierarchal structure, and its facility for using the capacity of human cognition to undertake paired comparisons to determine relative importance among a collection of criteria (i.e. indicators of capacity and sensitivity) (Eakin and Tapia, 2008).

Ramanathan (2001) did a step wise analysis of AHP for environmental impact assessment. The initial step of AHP model is decomposition of the problem into elements according to their common characteristics and the formation of a hierarchical model having different levels. The topmost level is the 'focus' of the problem or overall goal of the analysis, which is here vulnerability assessment or deriving the vulnerability indicators for fishing communities. The intermediate levels correspond to criteria and sub-criteria, and here the criteria are selected on the basis of five types of livelihood assets (see the following figure) and their relevance for explaining the sensitivity and adaptive capacity. While the lowest level contains the 'alternatives' or indicators for measurement, those are derived from a detailed literature review. Once the indicators of adaptive capacity and sensitivity are identified, in the next step the elements are compared through a pair wise judgmental matrix that helps to elicit weights for the indicators. The last and final step of the model is to aggregate the elements and to obtain final priorities or alternatives.

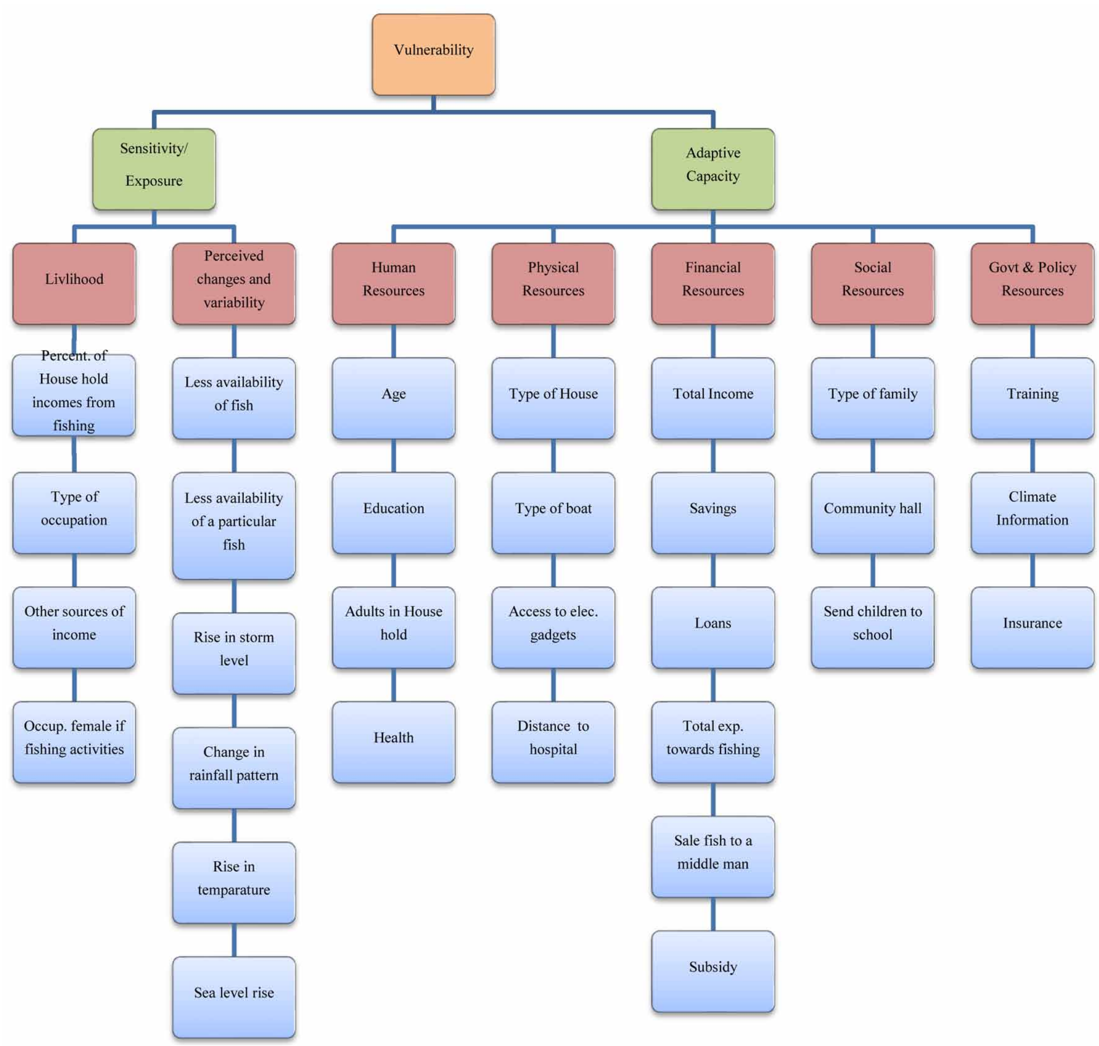
4.4. Indicators Selected for the Current Study

Vulnerability is a function of exposure (IPCC, 2001), sensitivity and adaptive capacity, however here the indicators of exposure and sensitivity are combined. Exposure and sensitivity are almost inseparable properties of a system and depend on the interaction between the characteristics of the system and on the attributes of the climate stimulus. Exposure and sensitivity reflects the resource use pattern and the dependency of livelihoods on climate-sensitive activities (Smith and Wandel, 2006; Ekin and Tapia, 2008).

The sensitivity and exposure indicators here are categorized into two: the livelihood indicators and indicators of perceived climate change and climate variability. The livelihoods of fishing communities in Mumbai are in danger because of the reduction in fish catch, and reduction in their income. Koli women those who had supported the family financially by engaging in selling and other marketing activities are losing their jobs because of the entry of migrants to marketing activities and because of the increase in fish export by using modern days storage facilities. The small and daily fishermen, those who do fishing within a few kilometers with their traditional and country boats are not getting enough fish to catch. Similarly, the owners of big boat and trawlers are facing stiff competition among themselves. Therefore the indicators of livelihood are carefully selected. The indicators for perceived climate change and variability are based on the observations of fishermen towards sea level rise, temperature rise, rainfall pattern, and availability of fish.

Adaptive capacity is the function of resources like access to information, technology, institutional capacity, wealth and finance, etc. The capacity of households to adapt helps them to counteract the sensitivity and thus reduces their vulnerability. Adaptive capacity is therefore a crucial factor in determining vulnerability. Adaptive capacity depends on the prevailing political, social and economic conditions and the indicators of adaptive capacity can be derived from these factors. The livelihood approach is used here as a starting point. The SLA is built upon five types of assets, or capitals: human, physical, financial, social/political, and governance related. These assets help households to mitigate risk and construct viable subsistence strategies. The indicators describing human factors in the study are age, education, number of adults, and health. Similarly types of house, types of boat, having electronic gadgets and distance to hospital are selected as the indicators of physical factors. Under financial resources the

Figure 1. Indicators of vulnerability, sensitivity and adaptive capacity selected for the current study



indicators are total income, savings, loan, total expenditure towards fishing, whether selling fish to middlemen and subsidy. The social resources are defined by indicators such as type of family (joint or nuclear family), existence of community hall in the society, and whether fishermen send their children to school. The indicators of government and policy resources are training provided by government to fishermen, climate information like provision for early warning and insurance towards loss of boats and loss of life.

The indicators are arranged in a hierarchical structure. There are four levels in the structure, the highest level is the overall goal of the analysis i.e. obtaining the weights of vulnerability indicators, the second level represents the two sub-components sensitivity and adaptive capacity, at the third level the indicators of sensitivity and adaptive capacity are described. Sensitivity indicators are of two categories, whereas the indicators of adaptive capacity is of five categories. At the lowest or final level of the hierarchy the indicators of overall vulnerability or alternatives selected for this study are presented.

4.5. Allocating Weights through Experts' Judgments

Once the appropriate indicators of sensitivity and adaptive capacity are identified, in the next step weights of these indicators are derived through pair wise comparison of these indicators and through experts' opinion. Each of the indicators derived is different and contribute differently towards vulnerability measurement. The indicators at each hierarchical level are arranged in pair wise comparison matrices (see the following matrix table). For the current study ten such comparison matrices are prepared and presented to experts' in the form of a questionnaire. These comparisons are based on judgments from the experts/researchers in the city belonging to higher learning institutes in the domain of social science, technical management, scientific research institutes, economics and development. The experts have worked in the area of environment, climate change and indicator studies. The comparison scale includes the fundamental 9-point scale of AHP. Where 1 represents equally importance, 3, 5, 7, 9 indicates moderately, strongly, very strongly and extreme important of one indicator (row) compared to another (column) and the intermediate scores 2, 4, 6, and 8 are used for expressing intermediate importance values.

After getting the component values for each indicator from experts, the relative weights of indicators are calculated following several steps (Saaty, 2008). The comparison matrix is two-dimensional, the diagonal of the matrix apparently takes the values of 1, the values on the upper side of diagonal are given by experts (blue color table 2) and the lower side of diagonal matrix is the reciprocal values (yellow color). For example, age of the households preferred very strongly in

Table 2. Pair wise comparison scores for indicators under human resources

Human Resources					
	Age	**Education**	**Adults in House Hold**	**Health**	**Priority Vector**
Age	1	1	7	3	0.44
Education	1	1	2	3	0.33
Adults in hh	1/7	1/2	1	1	0.11
Health	1/3	1/3	1	1	0.12
Sum of Columns	2.48	2.83	11	8	1

comparison to adults in the household, so it takes the value of 7 in the table and its reciprocal value is 1/7. Therefore only n (n-1)/2 entries need to be filled in by experts.

In the next step priority vector is estimated through principal eigen values. These values are the local relative weights of each indicator. These values can be derived by summing each column of the comparison matrix, and then dividing each value of the matrix by the sum of its column values. In the next step priority vector is obtained by averaging among each row. From the above table, it is clear that age is the more important indicator (44% preferred) under human resources category, followed by education (33% preferred). Health and adults in the households are preferred equally and obtained nearly same score.

Table 3. Local and global normalized indicator scores obtained from an expert

Vulnerability						
Sensitivity 0.5		**Adaptive Capacity 0.5**				
Livelihood Condition	**Perceived Change and Variability**	**Human Resources**	**Physical Resources**	**Financial Resources**	**Social Resources**	**Policy Resources**
0.83	**0.17**	**0.25**	**0.3**	**0.27**	**0.12**	**0.06**
0.42	0.08	0.13	0.15	0.14	0.06	0.03
Percent. of house hold income from fishing	Availability of fish	Age	Type of house	Total income	Type of family	Training
0.55	**0.28**	**0.48**	**0.33**	**0.44**	**0.73**	**0.44**
0.23	0.02	0.06	0.05	0.06	0.04	0.02
Type of occupation	Availability of a particular fish	Education	Type of boat	Savings	community hall	Climate Information
0.2	**0.3**	**0.26**	**0.39**	**0.17**	**0.16**	**0.49**
0.08	0.02	0.03	0.06	0.02	0.01	0.02
Other source of income	Rise in storm level	Adults in house hold	Access to elect. Gadgets	Loans	Send children to school	Insurance
0.17	**0.1**	**0.14**	**0.2**	**0.16**	**0.11**	**0.08**
0.07	0.01	0.02	0.03	0.02	0.01	0.01
Occu. female if fishing related activities	Change in rainfall pattern	Health	Distance of hospital	Total exp. towards fishing		
0.08	**0.18**	**0.12**	**0.08**	**0.12**		
0.03	0.01	0.02	0.01	0.02		
	Rise in temperature			Sale fish to a middlemen		
	0.1			**0.07**		
	0.01			0.01		
	Sea level rise			Subsidy		
	0.05			**0.04**		
	0			0.01		

The global weights are further calculated for each indicator by multiplying the priority vector by one of the components above. In the following table the global weights obtained from one expert is presented. At each level the sum of the local weights are equal to 1, and the sum of the global weights are equal to the global weight of the component above.

5. ESTIMATION OF VULNERABILITY INDICATORS

Vulnerability indicators are developed with the help of the primary data collected. However, these indicators are non-weighted indicators, derived by applying a simple aggregation method. Further the non-weighted indicator scores are compared with the weights assigned by experts. The survey questionnaires as well as data are of different scales and in order to assess over all vulnerability it is required to transform all the data into a uniform scale (0, 1). Therefore different value functions are used. The value functions reflect that vulnerability is higher as adaptive capacity decreases and sensitivity increases. A value of 1 indicates highest level of vulnerability whereas a value of 0 indicates highest adaptive capacity (or zero vulnerability) (Ekin and Tapia, 2008; Beinat, 1997). For assigning these values, again help of the experts as well as the review of literature are considered as basis (Ekin and Tapia, 2008). For example, if a fisherman is rather young or rather old he will lack maturity or will be less open to technical changes to adapt. Therefore those respondents below 25 years and above 65 years of age were given 1others given 0. In another case respondents belonging to Joint families possess more adaptive capacity and hence less vulnerable and scored 0 whereas respondents from nuclear families scored 1.

6. RESULTS AND DISCUSSIONS

After doing normalization, it is possible to calculate vulnerability scores of the household. The derived vulnerability scores can also be compared with the score and weights given by experts. The average vulnerability score for the villages surveyed is 0.65, and Madh village is found to be more vulnerable with the highest vulnerability scores of 0.67. Mahim village has the vulnerability score of 0.58. Similarly the average sensitivity score is 0.81 and average adaptive capacity score is 0.40.

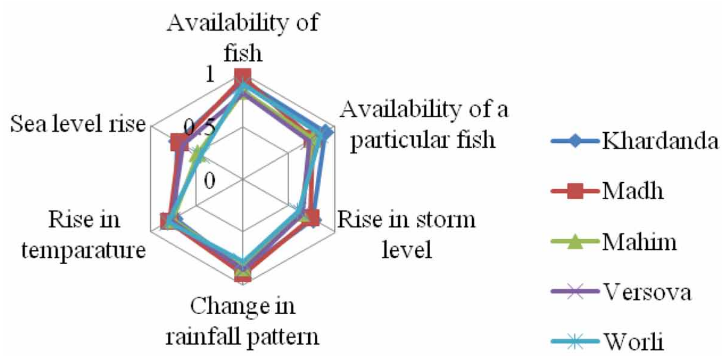
Non-weighted Indicator scores for perceived variability and change are presented in the following figure. The scores for sea level rise are low in all the villages. Whereas the vulnerability scores for less availability of fish is close to 1. However there is no significant difference in vulnerability scores among villages, i.e. all the villagers are receiving similar kind of changes.

Similarly indicator scores for adaptive capacity are divided under five categories based on five types of resources. The following figure (3 and 4

Table 4. Adaptive capacity, sensitivity and vulnerability scores for survey villages

Village	Vulnerability Scores	Sensitivity Scores	Adaptive Capacity Scores
Khardanda	0.61	0.82	0.39
Madh	0.67	0.85	0.48
Mahim	0.58	0.8	0.36
Versova	0.59	0.8	0.37
Worli	0.65	0.81	0.4

Figure 2. Indicator scores for perceived variability and change



shows the non-weighted adaptive capacity scores significantly varies among villages. The scores are very high under physical resources showing high vulnerability for Madh. Primary survey also pointed that in Madh most of the fishermen having motorized boat and in Madh there is no government hospital nearby. In case of emergency fishermen go to nearby private clinics. The use of electronic equipments like fish finder, GPS and satellite phone are also not less among fishermen in Madh. In case of human and financial resources the adaptive capacity scores are also low for Madh indicating a high vulnerability. Mahim also possess low adaptive capacity and high vulnerability for these indicators. On the other hand, in terms of access to electronic gadgets and other physical resources, Versova has a high adaptive capacity.

6.1. Comparing Vulnerability Scores with Weighted Scores

The weights given by experts towards various indicators of sensitivity and adaptive capacity as well as vulnerability are analyzed and compared with the non-weighted vulnerability score derived in the above section. The following figure shows the vulnerability sores given by three experts. The vulnerability scores among these three experts are quite equals, only the scores given by second expert is slightly lower than other two experts. The vulnerability scores given by experts depend on their knowledge on the area of their research work.

The following figure shows weights given by three experts towards five indicators of adaptive capacity. The weight given by first expert towards social indicator is high in comparison to other.

Figure 3. Indicator scores for adaptive capacity

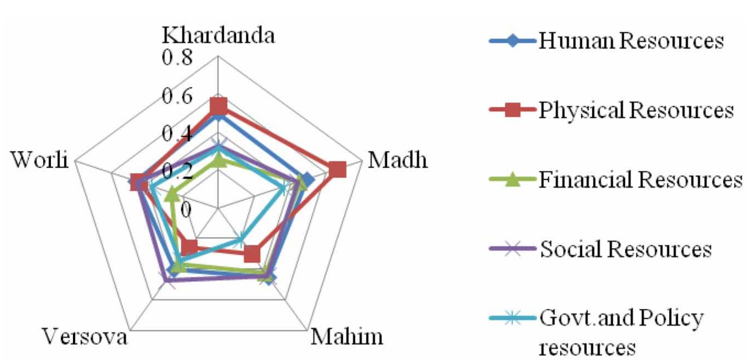


Figure 4. Indicator scores for physical resources

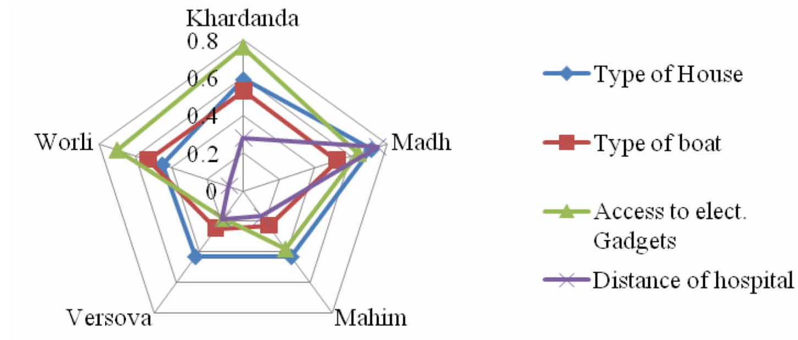


Figure 5. Weighted vulnerability scores by experts and non-weighted scores

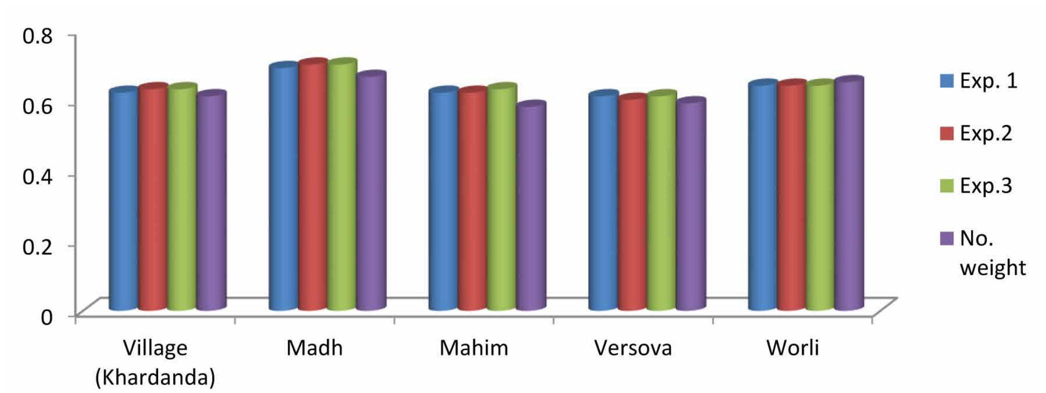
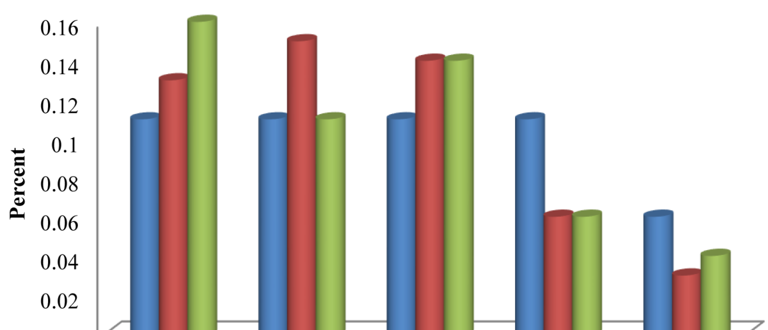


Figure 6. Weighted scores for indicators of adaptive capacity



	Human Resources	Physical Resources	Financial Resources	Social Resources	Govt.and Policy resources
Exp-1	0.11	0.11	0.11	0.11	0.06
Exp-2	0.13	0.15	0.14	0.06	0.03
Exp-3	0.16	0.11	0.14	0.06	0.04

6.2. Experts Consistency Level

Consistency of a judgment implies, if A is preferred to B, and B is preferred to C than A must be preferred to C. Human judgments are never consistence, according to Saaty a 10% inconsistency level is acceptable. The consistency levels for all the comparisons by experts are estimated. Some of the comparisons are found consistence with a value of 10 or less. Others are just above 10% level and can considered as good estimation. Few comparisons are also found to be inconsistence with high scores. The method of this consistency measurement is taken from Saaty (1980).

7. CONCLUSION

The literatures on vulnerability are multidisciplinary comprising broad areas of economics, sociology, geography, disaster management etc. There is a paradigm shift from top-down studies to bottom-up studies in the area of climate change impact and vulnerability assessment. Bottom-up studies are more localized and region specific studies. Although climate change is a global problem and initially researchers focused on mitigating climate change, but the need of the hour is adaptation and providing localized solutions for which a detailed discussion on the techniques to measure vulnerability and the extent of vulnerability is needed. This study incorporates a household vulnerability assessment in order to understand the diverse impacts of climate change on household behavior. The vulnerability scores derived for the Madh and Worli villages are high (0.67 and 0.65 respectively) in comparison to other fishing villages selected for this study. Under sensitivity and livelihood conditions four indicators are taken, however the scores for these indicators do not vary much among villages, although they show high vulnerability for the villages implying the percentage of income from fishing is the highest for all the fishermen, fishing is the major occupation and most of them do not have any other source of income. Similarly under perceived variability, less availability of fish, change in rainfall pattern, rise in temperature, and rise in storm level are perceived by all the fishermen, however in terms of perceived sea level rise the scores differ, and shows less vulnerability. Vulnerability scores for the indicators under physical resources, financial resources and government policy resources are higher for Worli and Madh showing high vulnerability and less adaptive capacity. This is due to the findings that in Worli and Madh villages' fishermen use more of motorized boats rather than mechanized ones as well as lack in terms of the use of electronic gadgets. This may also be due to the exploitation of fishermen by middle men and lack of proper fishing training provided by the government.

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APPENDIX

Table 5. Indicators of vulnerability and adaptive capacity (Adger et al., 2004)

Indicator	Variable	Proxy
Economic well being	National wealth	GDP per capita
	Inequality	GINI coefficient
	Economic autonomy	Debt repayments as a percentage of GDP
Health and nutrition	State support for health	Health expenditure per capita
		Public health expenditure
	Burden of ill health	Disability adjusted life expectancy
	General health	Life expectancy at birth
	Healthcare availability	Maternal mortality per 100 thousand
	Removal of economically active population	AIDS/HIV infection (% of adults)
	Nutritional status	Calorie intake per capita
	General food availability	Food production index
	Access to nutrition	Food price index
Education	Educational commitment	Education expenditure as % of GNP
		% of government expenditure
	Entitlement to information	Literacy rate (% of population over 15)
		Literacy rate (% of 15-24 year olds)
		Literacy ratio (female to male)
Physical infrastructure	Isolation of rural communities	Roads (km, scaled by land area with 99% of population)
	Commitment to rural communities	Rural population without access to safe water (%)
	Quality of basic infrastructure	Population with access to sanitation (%)
Governance-related factors	Priorities other than adaptation	Internal refugees (1000s) scale by population
	Effectiveness of policies	Control of corruption
	Ability to deliver services	Government effectiveness
	Willingness to invest in adaptation	Political stability
		rule of law
	Barriers to adaptation	Regulatory quality
	Participatory decision making	Voice and accountability
	Influence on political process	Civil liberties
		Political rights
Demographic and geographical	Coastal risk	Km of coastline (scale by land area)
		Population within 100km of coastline (%)
	Infrastructure/disease	Population density

continued on following page

Table 5. Continued

Indicator	Variable	Proxy
Agriculture	Dependence on agriculture	Agricultural employees (% of total population)
		Rural population (% of total)
		Agricultural employees (% of male population)
		Agricultural employees (% of female population)
	Agricultural self sufficiency	Agricultural production index
Natural resources and ecosystems	Environmental stress	Protected land area (%)
		Forest change rate (% per year)
		Percent forest cover
		Unpopulated land area
	Sustainability of water resources	Groundwater recharge per capita
		Water resources per capita
Technical capacity	Commitment to and resources for research	R&D investment (% GNP)
	Capacity to undertake research and understand issues	Scientists and engineers in R&D per million population

Chapter 6
Environmental Vulnerability to Climate Change in Mediterranean Basin:
Socio-Ecological Interactions between North and South

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ABSTRACT

The Mediterranean basin (MB) connects the south with the north and the East (Europe, Africa & Asia). It is a highly heterogeneous region where natural and anthropogenic activities interact in complex ways with climate variability. Climate change (CC) impacts are already defined on the Mediterranean. That is why the time has come to formulate a long-term plan for adaptation to CC of the MB. In this chapter the author aims (i) the assessment of the environmental vulnerability under CC provided in the BM during the last 30 years, (ii) the determination of environmental vulnerability indicators that the author call Major Common Indicators (MCI), and (iii) identification of adaptation strategies based on these indicators. For this analysis the author used the results of the Environmental Vulnerability Index (EVI), developed by SOPAC. In this paper, the author extracted, compiled, compared and analyzed the data of the EVI of 8 selected Mediterranean countries; 4 countries in North Africa (Morocco, Algeria, Tunisia and Egypt) and 4 Southern Europe (Spain, France, Italy and Greece).

INTRODUCTION

This chapter highlights how climate change, coupled with the socio-economic conditions, can amplify vulnerability in the developed and developing countries. It is an attempt to identify and better understand the range of factors that affect the environmental vulnerability to climate change, and make the link between population trends and environmental health. Globally, the Mediterranean basin is a concrete example where the effect of climate change is quite obvious. This region is a popular tourist destination because is rich in both natural resources and cultures. The

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Mediterranean Sea connects three continents: Europe, Africa and Asia. It is recognized as one of the most sensitive to climate change (CC), with occurring impacts close to environmental limits. The resilience of the ecosystems and biodiversity facing occurring and future CC impacts is reduced due to ever-increasing anthropogenic pressures (UNEP-MAP RAC/SPA, 2009). The Intergovernmental Panel on Climate Change (IPCC) employs a concept of vulnerability that characterises the effects of climate stresses for coupled socio-ecological systems in a transdisciplinary way (Parry, 2007). The IPCC concept defines vulnerability as the susceptibility of a system to be harmed by climate variability and change including its exposure, sensitivity and ability to cope with or adapt to adverse effects (Sietz, 2011). While after Jäger *et al.* (2007), vulnerability is defined as encompassing the effects of natural and anthropogenic stimuli impacting upon ecosystem functioning and human well-being. Otherwise, regional environmental vulnerability assessment still remains a great challenge (Boughton et al., 1999). Wang, (2008) reports also in this context that studies addressing regional environmental vulnerability evaluations are limited.

The vulnerability assessment is the first step in any sustainable policy to address the variability and CC (Messouli, 2013). But this vulnerability assessment requires the use of indicators and indices to standardize more information to give a comprehensive and integrated view of the state of the environment. The Vulnerability or the potential for harm can be assessed as a function of exposure to change, ecosystem sensitivity and the adaptive capacity of both people and biodiversity (UNEP WCMC, 2003). In this context, the environmental vulnerability index (EVI) for 8 selected countries in the Mediterranean basin was studied (4 African countries: Morocco, Algeria, Tunisia and Egypt and 4 the European countries: Spain, France, Italy and Greece). The EVI is a numerical index that reflects the status of a country environmental vulnerability. This EVI is among the first tools developed to focus environmental management at the same scales that environmentally-significant decisions are made, and focus them on outcomes at the scale of entire countries (EVI, 2003). Vulnerability has received international recognition as an issue of central concern to the sustainable development of countries (EVI, 2003). The factors affecting the degree of vulnerability can include remoteness, transboundary issues, geographic dispersion, natural disasters, a high degree of economic openness, small internal markets and a limited or damaged natural resource base (EVI, 2003). The EVI is based on 50 indicators of environmental vulnerability. Each indicator is rated on a scale of 1–7, with 7 being the most vulnerable and 1 being the least. The EVI focuses on the vulnerability of the environment to natural risks and to human mismanagement, including the effects on the physical and biological aspects of the ecosystems, diversity, populations and organisms, communities, and species (UNEP, 2001). It was also decided that vulnerability indices should be simple to build and based on indicators that are easy to comprehend, intuitively meaningful, and suitable for inter-country comparisons that reflect the relative vulnerability of countries (Pratt, 2000). By using the average values obtained from the vulnerability indicators of the EVI index, we will identify common vulnerability indicators of the Mediterranean selected countries and use the appellation "Major Common Indicators", for all indicators having a score equal or higher than 5 and are common between the 8 selected countries. The objectives of this chapter are defined as follows:

- Assessment of the environmental vulnerability related to impacts of climate change and anthropogenic pressure in order to develop plans and programs of measures;
- Comparison of environmental vulnerability for the selected Mediterranean countries and;

- Determination of principals Mediterranean common indicators for a common vision in Mediterranean basin.

Basically, this chapter gives a stratification of information on common indicators in the Mediterranean and inventories indicators that have an effect on the state of the environment of each selected country and for the entire region. It also helps guide scientific research and follow-up actions for the environment.

The structuration of this chapter is as follow:

- The first section of this chapter introduces an overview of the study area, and provides general information about the Mediterranean basin (main factors taking place in the region);
- The second section presents the methodology used;
- The third section identifies indicators of vulnerability and discuss the existing interactions between human factors and the Mediterranean ecosystems;
- The fourth section analyzes the applicability of EVI tool at local scale as concrete responses to specify the problems and vulnerability indicators mentioned in the third part;
- Finally, it discusses the recommendations and prospects for the countries of North Africa and also for the countries of southern Europe, in order to guide adaptation policies to climate change.

MATERIAL AND METHODS

Study Area

This chapter provides a comparative study of the environmental vulnerability of 8 Mediterranean countries, including 4 located in the African shores of the Mediterranean Sea (Morocco, Algeria, Tunisia and Egypt) and 4 countries in the European shore of the sea (Spain, France, Italy and Greece).

The Mediterranean basin connects three continents (Africa, Europe and Asia), whose countries share the following elements (Brauch, 2010):

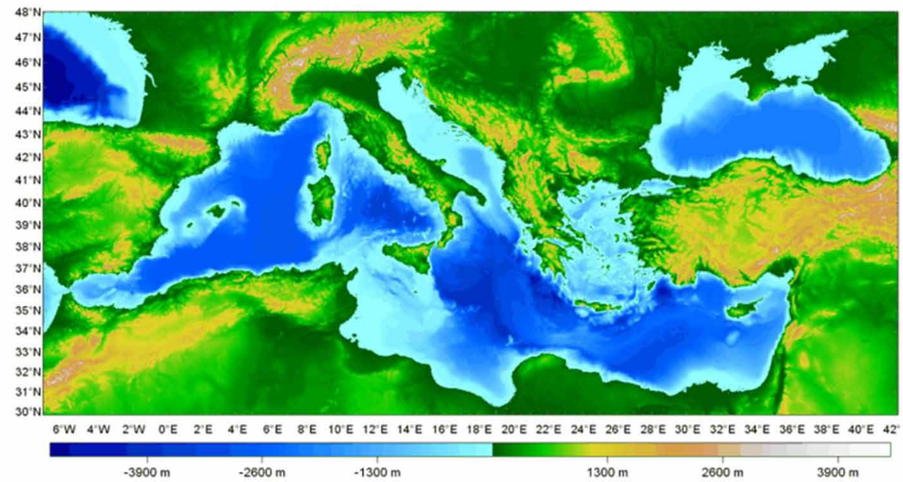
1. Common ecological features (climate, landscape) and a shared environmental responsibility, which is challenged by urbanization, demography, and tourism that have contributed to an "environmental crisis";
2. A common history;
3. A distinct Mediterranean economy; and
4. Relatively homogeneous cultures.

Geography and Sociology

The Mediterranean Sea is an intercontinental sea connecting Europe to the north, Africa to the south, and Asia to the east (Figure 1). It has an east to west extent of some 3860 km and a maximum width of about 1600 km; generally shallow, with an average depth of 1500 m, it reaches a maximum depth of 5150 m off the southern coast of Greece[1]. It is a region that once was the centre of the world, the cradle of the civilizations of Egypt, Crete, of Hellenism and the Roman Empire and of three monotheistic religions of Jews, Christians and Muslims. For millennia, the Mediterranean has been a unique geographical space but– except for the Roman Empire – it has been a divided region politically, economically and culturally (Brauch, 2010).

The region is characterized by high geopolitical and socio-economic heterogeneity and differences related to institutional, scientific and technical potential, capacities and expertise, such as a 10-fold difference in GDP between most developed countries and those less developed, and the 3-fold up to 6-fold difference of GNP per capita between W European countries and the other ones (WWF, 2005). Overall, more than half the population lives in countries on the southern shores of the Mediterranean, and this proportion

Figure 1. Topographic and bathymetric map of the Mediterranean basin
Map produced by G. Pavan at CIBRA/UNIPV with Ocean Map by combining a number of different datasets (Source: http://www.unipv.it/cibra/edu_Mediterraneo_uk.html)



is expected to grow to three quarters by 2025 (UNEP/MAP/MED POL, 2005).

The diversity of socio-economical systems is evidenced by the ecological footprints of the Mediterranean states. Ecological Footprint analysis is an accounting framework relevant to this research question; it measures human appropriation of ecosystem products and services in terms of the amount of bioproductive land and sea area needed to supply these products and services (Ewing *et al.* 2010). The 8 Mediterranean selected countries can be separated into two groups (Table 1):

1. Middle-income countries, with low Human Development Indices (HDIs) and small ecological footprints plus substantial progress in HDI, in the 4 Mediterranean selected countries of Africa continent (Morocco, Algeria, Tunis and Egypt); and
2. High-income countries, with high HDIs and large ecological footprints. These are the 4 Mediterranean selected countries (Spain, France, Italy and Greece).

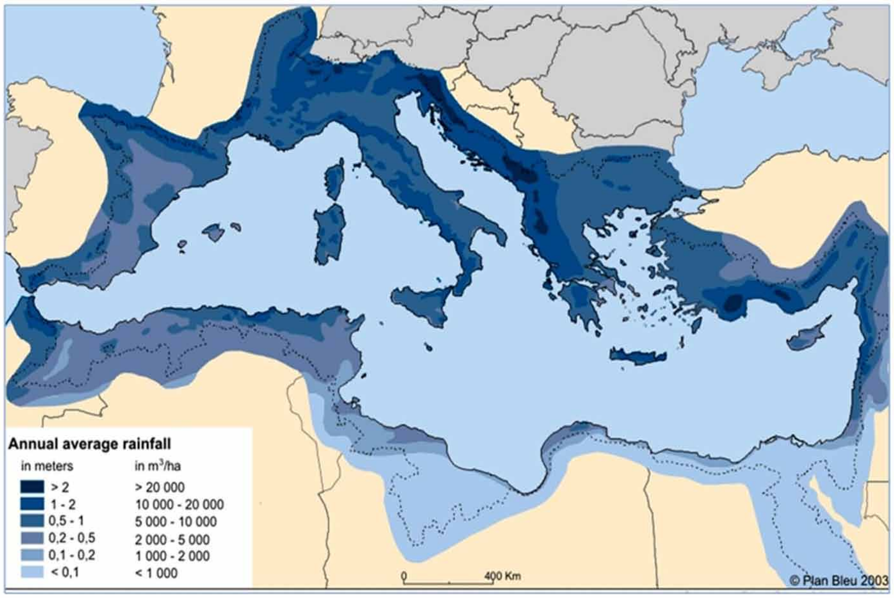
Climate

The main physical and physic-geographical factors controlling the special distribution of the climatic conditions over the Mediterranean are the atmospheric circulation, the latitude, the

Table 1. Human development and ecological footprint for the selected Mediterranean countries. Source of data: Global Footprint Network (http://www.footprintnetwork.org/)

Region	North Africa	South Europe
Countries	Morocco, Algeria, Tunis and Egypt	Spain, France, Italy and Greece
Human Development Index 2007	Medium Human Development 0,55-0,67	Very High Human Development 0,8-0,9
Footprint Network (Hectares per capita)	1-2	5-6

Figure 2. Average rainfall distribution in the Mediterranean basin
Source: Plan bleu, 2003; plan bleu, Margat, 2004

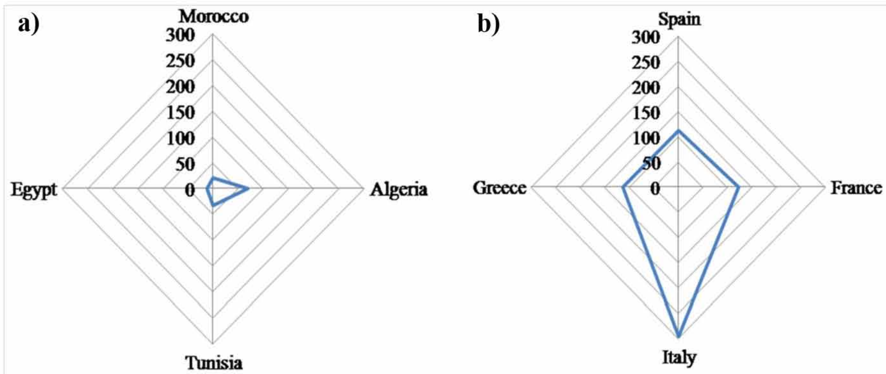


altitude and, generally, the orography, the Atlantic and Mediterranean sea surface temperature (SST) distribution, the land sea interactions and smaller-scale processes (Xoplaki et al, 2000). The region's climate is the typical "Mediterranean", sub-tropical and temperate one, with significant differences between the Northern and Southern coasts. The climate is already under strong influence of CC, often presently defined as "climate variability" (UNEP-MAP RAC/SPA, 2009). The Mediterranean region lies in an area of great climatic interest (Dafka, 2013). It is influenced by some of the most relevant mechanisms influencing the global climate system: it marks a transitional zone between the desert of North Africa, and central northern Europe (Bolle, 2003). The strong summer-winter rainfall contrast, which increases from north to south and from west to east, is the major characteristic of the Mediterranean climate (UNEP/MAP/MED POL, 2003). In fact, the distribution of precipitation on the map in Figure 2 shows that it is important in the European south side than in the Mediterranean Africa side.

In the latter side and in entire continent (Africa), the complexity of the continent climatic system and the interaction of this system with many socio-economic challenges such as endemic poverty, HIV/AIDS, poor governance, ecosystem degradation, ethnic conflicts and population growth; could undermine the ability of communities to adapt to climate change (GIEC, 2007). The African selected countries are particularly vulnerable to global warming because of their geographical position and their dependence on climate-sensitive economic sectors (Osberghaus & Baccianti, 2013) like agriculture. The Figure 3 shows a quantification of rainfall in the selected countries, left (Figure 4a) for the 4 countries of North Africa and right (Figure 4b) for southern European countries; which illustrates the distribution mentioned in Figure 3.

The distribution of the Mediterranean-climate zone in the Mediterranean Basin, and Isolines of the mean minimum temperature for the coldest month (m, 7, 3, 0, -3 and -7º C), define the following climatic environments (Figure 4):

Figure 3. Yearly average precipitation (yearly average fluxes in km3): a) African selected countries; b) European selected countries
Data source: http://medhycos.mpl.ird.fr/en/t1.resi&gn=Margat.inc&menu=fresimf.inc.html



- Infra-Mediterranean (in red; m > 7)
- Thermo-Mediterranean (in orange; 3 < m < 7º C): shrublands
- Meso-Mediterranean (in green; 0 < m < 3) evergreen oak forests
- Supra-Mediterranean or sub-Mediterranean (in yellow; -3 < m < 0): winter semi-deciduous forests
- Mountain-Mediterranean (in black; -7 < m < -3): conifer forest
- Areas with m < -7º C (Oro-Mediterranean, m < -7; dwarf-shrubs) are small areas at the tops of mountains (not shown).

When temperatures are high for several months, as illustrated in the Figure 5 by red and orange colors and rainfall is low, create droughts that prevent vegetation to grow. Within its natural boundaries, the Mediterranean climate implies complex interactions between global climate

Figure 4. Distribution of the Mediterranean-climate zone in the Mediterranean Basin
Source: (Quézel & Médail, 2003)

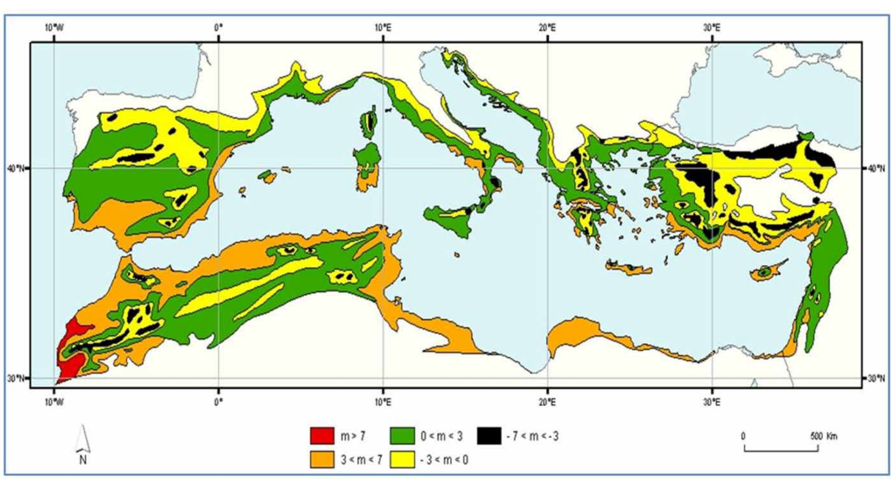
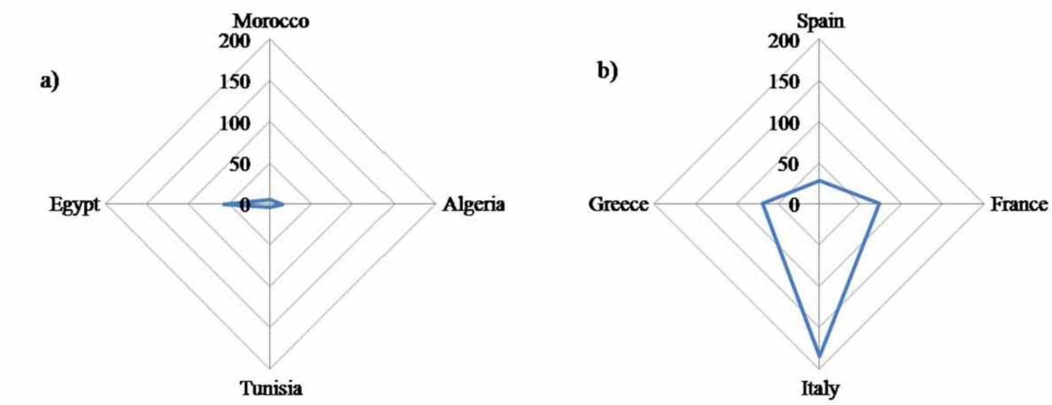


Figure 5. Total fresh water resource (water surface and groundwater) - Yearly average water resource in km3: a) African selected countries, b) European selected countries
Source of data: http://medhycos.mpl.ird.fr/en/t1.resi&gn=Margat.inc&menu=fresimf.inc.html



change and regional impacts that will negatively reinforce ongoing processes of desertification (Brauch, 2010). The Mediterranean area is climate-sensitive region which is climatically stressed by limited water resources and extremes of heat which help to create or exacerbate existing sociopolitical tensions (Mann, 2002). Especially the climatic situation of the selected countries of Africa causes a lack of water and overexploitation of natural resources, which lead to a loss of biodiversity. Therefore, the soil becomes poor; species disappear, which increases food insecurity and creates conflict.

Hydrology

The water resources in the study area depend on the climatic parameters (temperature and precipitation); the data provided by the *MEDHYCOS* project lead to make the comparison of the total available water between the two countries groups (south and north). The Figure 5 illustrates the large difference in the total fresh water resource between the two sides (south Europe and North African selected countries).

The African side shows small amount of total fresh water compared to European selected countries. The water supply in countries of Africa both in quality and quantity are critical to the social and economic welfare. However, water resources are under high pressures, including population growth and degradation of watersheds caused by a change in land use. The hydrology in Mediterranean countries, is also threatened by the results of human activity, such as pollution and sediment flow from intensive agriculture and industrial development, both local and upstream (UNEP/MAP/MED POL, 2005).

Biodiversity

The Mediterranean Sea has been recognized as one of the global biodiversity hot spots (UNEP MAP RAC/SPA, 2009). While covering 1,5% of global surface, it hosts 7% of global marine fauna, 18% of marine flora (out of it 28% endemic), about 12.000 marine species, 600 fish species (out of it 81 cartilaginous ones), 3 turtle species, 12 whale species, 19 cetaceans/seals listed as endangered, birds – 33 breeding wintering species (out of them 9 endangered), 13.000 marine endemic plants… (UNEP/MAP MEDPOL, 2005). The Mediterranean ecosystems among the most vulnerable to CC in Europe close to environmental limits (droughts, extreme events, wildfires, inundation). Between 60 and 80% of current species may not persist in Mediterranean under global MTR 1.8ºC (Berry, 2008). The regional ecosystem is characterized by limited resources not supporting over-exploitation (UNEP-MAP RAC/SPA, 2009). Here it should be kept in mind that in 2001 an ecological deficit was recorded in all riparian countries – the environmental capital being spent faster than it is renewed (UNEP-MAP BP Earthscan, 2005). Concerning the Mediterranean, the key facts are (UNEP-MAP RAC/SPA, 2009):

1. The region is among the richest in biodiversity of global importance, rich with endemism and autochthonous species;
2. Biodiversity is rapidly declining, due to land-use change and other anthropogenic impacts, climate change, invasive species, overexploitation and pollution;
3. A great number of globally important habitats, populations, species is already endangered, many species under risk of extinction;

The Mediterranean Sea and surrounding lands are characterized by a relatively high degree of biological diversity (UNEP, 1999). The fauna includes many endemic species and is considered richer than that of Atlantic coastal areas (Bianchi and Morri, 2000). The loss of biodiversity, declines in productivity, and contamination by pollutants do not affect only the marine systems and how well they function; they also affect human health, human economies, and the very fabric of these coastal societies (PNUE/PAM, 2012). There is a consensus that biodiversity plays fundamental role in ecosystem functioning. In fact, it provides many key benefits to humans. However, the biodiversity loss has negative effects on many aspects of human well-being, such as vulnerability to natural disasters, access to clean water and food security (MEA, 2005).

Agriculture, Mining, and Manufacturing

Agriculture in the Mediterranean Basin, despite many different sub-climates, is mainly rain-fed; Cereals, vegetables, and citrus fruits account for over 85% of the Mediterranean's total agricultural production (UNEP/MAP/BP/RAC, 2009). Cultivation of other products, such as olives for olive oil and grapes for wine, also occupies a significant amount of agricultural land (Leff et al, 2004). The total surface area of cultivated land in the Mediterranean Basin, however, has remained approximately stable over this period (PNUE/PAM, 2012). For the Mining and manufacturing sector, the lack of major iron and, especially, coal reserves within the Mediterranean Basin influenced the industrial development path of the countries surrounding the Mediterranean Sea (UNEP/MAP, 2012). Steel production has been concentrated in the north (Italy, France, Spain, and Greece), with a few producers in the south (Egypt, Algeria and Tunisia) (UNEP/MAP, 2012). Other mining activity in the Mediterranean has focused on mercury (Spain), phosphates (Morocco, and Tunisia), lead, salt, bauxite (France and Greece) and zinc (Spain and Morocco) (EEA and UNEP, 1999). Across the Mediterranean, coastal urbanization involves the production of waste (sewage and solid waste). In many cases, habitat alteration led to the loss of biodiversity and wetlands as well as environmental degradation posing a serious threat to many aquatic species. In addition of the coastal urbanization, the agriculture, the industry, and mining have a direct impact on all ecosystems of the Mediterranean basin (MB).

Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes (Ngwa *et al.* 2015). POPs persist in the environment, are capable of long-range transport, bioaccumulate in human and animal tissue, biomagnify in food chains, and have potentially significant impacts on human health and the environment (UNEP, 2010). The concentration of the POPs is concentrated especially in the European region because the geographical distribution of industrial activities in the Mediterranean Basin is uneven, with most industry concentrated in the northwest, particularly in Italy, France, and Spain (L'Europe, 2014).

METHODOLOGY

Analysis of environmental vulnerability of the Mediterranean basin is performed using the results collected from the environmental vulnerability index (EVI) profiles of the 8 selected countries in this basin; four countries in North Africa (Morocco, Algeria, Tunisia and Egypt) and four in Southern Europe (Spain, France, Italy and Greece). In this chapter, we extracted, compiled, compared and analyzed the indicators scores of the EVI profiles of these 8 selected Mediterranean countries. We report here that the launching of the final presentation of the EVI based on 50 indicators was at the Mauritius International Meeting on 12 January 2005; where more than 300 experts contributed to the development of the EVI (www.vulnerabilityindex.net). After these profiles (2005), the EVI uses 50 indicators for estimating the vulnerability of the environment of a country. Data for each indicator is located within an EVI scale which ranges between 1-7, where the value EVI=1 indicates low, and EVI=7 indicates extreme vulnerability for a country relating to an indicator. Table 1 outlines the 50 indicators that make up the environmental vulnerability index. The EVI index was designed to summarize a wide range of environmental vulnerability information about an individual country, and assesses the environmental vulnerability of Mediterranean basin countries. To be consistent with the methods of the South Pacific Applied Geosciences Commission, the calculation of the indices was based on the units of measurement used in the individual indices (Gowrie, 2003), see Table 2.

The Table 3 gathered the 50 indicators in 7 categories. Each category has a specific number of indicators, for example the climate change category has 13 indicators and biodiversity has 19 etc.

The Table 4 classifies the mentioned indicators in three aspects of vulnerability (Hazards, Resistance and Damage)

RESULTS AND DISCUSSION

The environmental vulnerability Index is a tool that involves interdisciplinary synthesis at a high level of data aggregation. It allows the synthesis of key indicators that affect the Mediterranean environment and highlights the current and potential impacts of human activities. It is designed to enable decision makers to do an integrated synthesis at different scales, nationally and also regionally for release comparisons between countries of the same region). The Mediterranean is recognized as one of regions most sensitive to CC. In addition, the pollution, the increasing pressure of other human activities and unsustainable development further reduces the resilience and adaptability of ecosystems, habitats and biota related to occurring and future CC impacts (UNEP-MAP RAC/SPA, 2009).

Qualitative Analysis of Environmental Vulnerability in Mediterranean Selected Countries Using the 7 Sub-Indices

Based on the analysis of the data extracted, the overall environmental vulnerability index (EVI) for the Mediterranean zone was determined to be between 275 in Algeria and 386 in Italy. The sub-indices of climate change for Algeria for example was calculated to be 3.92, the biodiversity

Table 2. Summary of environmental vulnerability indices (EVI) for the Mediterranean countries, extracted from the EVI calculator

N°	Type	Description	Unit
1	Wind	Average annual excess wind over the last five years (summing speeds on days during which the maximum recorded wind speed is greater than 20% higher than the 30 year average maximum wind speed for that month) averaged over all reference climate stations.	days/yr
2	Dry	Average annual rainfall deficit (mm) over the past 5 years for all months with >20% lower rainfall than the 30 year monthly average, averaged over all reference climate stations.	mm / station / yr
3	Wet	Average annual excess rainfall (mm) over the past 5 years for all months with >20% higher rainfall than the 30 year monthly average, averaged over all reference climate stations.	mm/station/year
4	Hot	Average annual excess heat (degrees Fahrenheit) over the past 5 years for all days more than 9F (5°C) hotter than the 30 year mean monthly maximum, averaged over all reference climate stations.	degrees/yr
5	Cold	Average annual heat deficit (degrees) over the past 5 years for all days more than 5°C cooler than the 30 year mean monthly minimum averaged over all reference climate stations.	degrees / yr
6	SST	Average annual deviation in Sea Surface Temperatures (SST) in the last 5 years in relation to the 30 year monthly means	degrees / yr
7	Volcano	Cumulative volcano risk as the weighted number of volcanoes with the potential for eruption greater than or equal to a Volcanic Explosively Index of 2 (VEI 2) within 100km of the country land boundary (divided by the area of land).	VEI Unit / million km^2
8	Earth-quake	Cumulative earthquake energy within 100km of country land boundaries measured as Local Magnitude (ML) ≥ 6.0 and occurring at a depth of less than or equal to fifteen km (≤15km depth) over 5 years (divided by land area)	Number ML >= 6, Depth <= 15km
9	Tsunami	Number of tsunamis or storms surges with run-up greater than 2 meters above Mean High Water Spring tide (MHWS) per 1000km coastline since 1900	Number since 1900 >2m run-up
10	Slides	Number of slides recorded in the last 5 years (EMDAT definitions), divided by land area	Slides / million km^2land
11	Land	Total land area (km^2)	sq km
12	Dispersion	Ratio of length of borders (land and maritime) to total land area	km / 1000 km^2
13	Isolation	Distance to nearest continent (km)	Km
14	Relief	Altitude range (highest point subtracted from the lowest point in country)	M
15	Lowlands	Percentage of land area less than or equal to 50m above sea level	%
16	Borders	Number of land and sea borders (including EEZ) shared with other countries	Number
17	Imbalance	Ecological Imbalance as weighted average change in trophic level since fisheries began (for trophic level slice ≤3.35)	
18	Openness	Average annual USD freight imports over the past 5 years by any means per km^2 land area	USD Thousands / km^2 land
19	Migratory	Number of known species that migrate outside the territorial area at any time during their life spans (including land and all aquatic species) / area of land	Spp / 1000 km^2 land
20	Endemics	Number of known endemic species per million square km land area	Spp / 1,000,000 km^2 land
21	Introductions	Number of introduced species per 1000 square km of land area	Spp / 1,000 km^2 land
22	Endangered	Number of endangered and vulnerable species per 1000 sq km land area (IUCN definitions)	Spp / 1,000 km^2 land

continued on following page

Table 2. Continued

N°	Type	Description	Unit
23	Extinctions	Number of species known to have become extinct since 1900 per 1000 sq km land area (IUCN definitions).	Spp / 1,000 km^2 land
24	Vegetation	Percentage of natural and regrowth vegetation cover remaining (include forests, wetlands, prairies, tundra, desert and alpine associations).	% of original cover
25	Loss Veg	Net percentage change in natural vegetation cover over the last five years	% change (-ve = loss)
26	Fragment	Total length of all roads in a country divided by land area	km / km^2
27	Degradation	Percent of land area that is either severely or very severely degraded (FAO/AGL Terrastat definitions)	%
28	Reserves	Percent of terrestrial land area legally set aside as no take reserves	% of land area
29	MPAs	Percentage of continental shelf legally designated as marine protected areas (MPAs)	%
30	Farming	Annual tonnage of intensively farmed animal products (includes aquaculture, pigs, poultry) produced over the last five years per square km land area.	t / km^2 / yr
31	Fertilizers	Average annual intensity of fertilizer use over the total land area over the last 5 years.	kg / km^2/ yr
32	Pesticides	Average annual pesticides used as kg/km^2/year over total land area over last 5 years.	kg / km^2/ yr
33	Biotech	Cumulative number of deliberate field trials of genetically modified organisms conducted in the country since 1986	Total number trials
34	Fisheries	Average ratio of productivity: fisheries catch over the last 5 years	t C / km^2/ yr: t fish / sq km / yr
35	Fish Effort	Average annual number of fishers per kilometer of coastline over the last 5 years	fishers / yr / km coast
36	Water	Average annual water usage as percentage of renewable water resources over the last 5 years	%
37	Air	Average annual SO_2 emissions over the last 5 years	t / km^2 / yr
38	Waste	Average annual net amount of generated and imported toxic, hazardous and municipal wastes per square km land area over the last 5 years	t/km^2/yr
39	Treatment	Mean annual percent of hazardous, toxic and municipal waste effectively managed and treated over the past 5 years.	%
40	Industry	Average annual use of electricity for industry over the last 5 years per square km of land	toe / km^2
41	Spills	Total number of spills of oil and hazardous substances greater than 1000 litres on land, in rivers or within territorial waters per million km coast during the last five years	Number of spills / million km coasts
42	Mining	Average annual mining production (include all surface and subsurface mining and quarrying) per km^2 of land area over the past 5 years.	t / km^2 / yr
43	Sanitation	Density of population without access to safe sanitation (WHO definitions)	people / km^2
44	Vehicles	Number of vehicles per square km of land area (most recent data)	vehicles / km^2
45	Density	Total human population density (number per km^2 land area)	people / km^2
46	Growth	Annual human population growth rate over the last 5 years	%
47	Tourists	Average annual number of international tourists per km^2 land over the past 5 years.	people/km^2/yr
48	Coastal	Density of people living in coastal settlements (i.e. with a city centre within 100km of any maritime or lake* coast).	people/km^2
49	Agreements	Number of environmental treaties in force in a country	Treaties
50	Conflicts	Average number of conflict years per decade within the country over the past 50 years.	Average conflict years / decade

Table 3. 50 EVI indicators are grouped into seven categories: sub-indices

Climate Change	CC	13 Indicators
Biodiversity	CBD	19
Water	W	12
Agriculture / Fisheries	AF	20
Human Health Aspects	HH	6
Desertification	CCD	11
Exposure to Natural Disasters	D	11

sub-indices was 2.84, the Exposure to Natural Disaster index was measured at 2.64, and the Desertification was found to be 3.91, Agriculture / Fisheries is 2.95, Human Health Aspects is 2, and Water 3.58 like showed in Table 5.

Figure 6 and Table 6 give a vulnerability comparison between all selected countries for the seven categories or sub-indices (climate change, biodiversity, Exposure to Natural Disaster, Desertification, Agriculture / Fisheries, Human Health Aspects, and Water).

The total scores of all selected countries are illustrated in Table 7, based on the EVI scores extracted from the EVI Calculator developed by SOPAC (Table 8), it should be noted that the

Table 4. The EVI's 50 smart indicators arranged by aspects of vulnerability (numbers assigned by the South Pacific Applied Geoscience Commission [SOPAC])

Hazards	Resistance	Damage
1 to 10 18, 25 28 to 29 and 30 to 44 46 to 47 and 49	11 to 16 19 to 20	17 21 to 24 26 to 27 45, 48 and 50

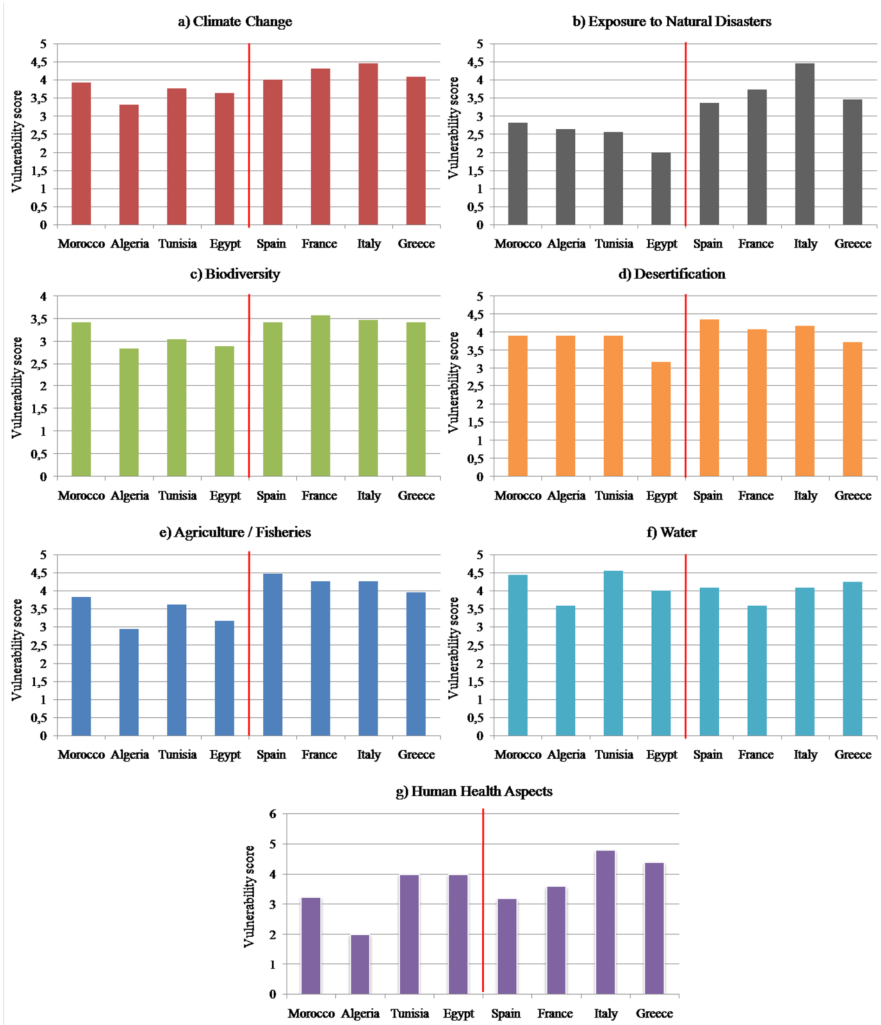
vulnerability indices were subject to observation error, given that the data were not derived solely from field data but in many cases from previously documented data sources (Gowrie, 2003). Because of the dynamic nature of the environment, this EVI is not a fixed value, and it can change in the future to reflect changes in the environmental and man-made forces that influence it (Gowrie, 2003).

After the Table 7, Italy is the most vulnerable in south Europe side. Its vulnerability is especially due to the impact of climate change and Exposure to Natural Disasters sub-indices. The Italy is active and subject to frequent earthquakes, for example Etna (in Italy) is one of the most active volcanoes in the world (Zdruli, 2011). This high vulnerability is exacerbated by anthropogenic factors (tourism pressure and population density). For the selected

Table 5. Environmental vulnerability index (EVI) by category scores

	Morocco	Algeria	Tunisia	Egypt	Spain	France	Italy	Greece
Climate Change	3.92	3.31	3.77	3.64	4	4.31	4.46	4.08
Exposure to Natural Disasters	2.82	2.64	2.55	2	3.36	3.73	4.45	3.45
Biodiversity	3.42	2.84	3.05	2.89	3.42	3.58	3.47	3.42
Desertification	3.91	3.91	3.91	3.18	4.36	4.09	44.18	3.73
Water	4.445	3.58	4.55	4	4.08	3.58	4.08	4.25
Agriculture / Fisheries	3.83	2.95	3.61	3.16	4.47	4.26	4.26	3.95
Human Health Aspects	3.25	2	4	4	3.20	3.6	4.8	4.4

Figure 6. The 50 indicators grouped into seven categories or sub-indices



countries of North Africa side, Morocco is the most vulnerable. In fact, the increasing drought severity and frequency, coupled with industrial pollution and the growth of Morocco's agricultural exports, mean that demand for water of sufficient quality and quantity is increasing (CLICO, 2012). A high level of attention and effort has been devoted to developing policies and management structures that ensure adequate water supply for public and industrial needs (CLICO, 2012).

The Hazards index for MB countries was determined to be 2.73 in Algeria and 4.06 in Italy, the resistance index was 2.13 in Tunisia and 3.5 in Italy, and the damage index was found to be 2.80 in Tunisia and 3.5 In Italy (Table 9).

The data of the Table 9 are presented in Figure 7.

The Figure 7 illustrates well the difference between European and African selected countries in Hazards, Resistance and Damage. The European selected countries are more exposed to Hazards

Table 6. Comparison of environmental vulnerability between all selected countries

	African Selected Countries	European Selected Countries
Climate change	Morocco is the most vulnerable to climate change followed by Tunisia, Egypt and Algeria.	Italy is the most vulnerable in all of Mediterranean basin followed by France, Greece and Spain.
Exposure to Natural Disaster	Morocco is the most vulnerable followed by Algeria, Tunisia and Egypt.	Italy is the most vulnerable in all of Mediterranean basin followed by France, Greece and Spain.
Biodiversity	Morocco is the most vulnerable to Biodiversity followed by Tunisia, Egypt and Algeria.	France and Italy are the most vulnerable to Biodiversity followed by France, Greece and Spain.
Desertification	Morocco, Algeria and Tunisia have the same vulnerability to Desertification followed by Egypt.	Spain is the most vulnerable in all of Mediterranean selected countries followed by Italy, France and Greece.
Agriculture and fisheries	Morocco is the most vulnerable followed by Tunisia, Egypt and Algeria.	Spain is the most vulnerable in all of Mediterranean basin followed by Italy, France and Greece.
Water	Tunisia is the most vulnerable to Water in all of Mediterranean selected countries followed by Morocco, Egypt and Algeria.	Greece is the most vulnerable to Water indicators in all of Mediterranean basin followed by Italy, Spain and France.
Human Health Aspects	Tunisia and Egypt are the same vulnerability to Human health aspects followed by Morocco, and Algeria	Italy is the most vulnerable to Human health aspects in all of Mediterranean basin followed by Greece, France and Spain.

and damage than African countries, concerning the resistance aspect, the European countries are more resistant than African countries.

Comparison of Vulnerability Indicators and Identification of the Major Common Indicators (MCI) in Mediterranean Basin

The scores for each indicator for the 8 countries of the Mediterranean and the sub-indices classification (climate, geology, geography, ecosystem services, and anthropological) lead to develop two types of comparisons: a comparison between countries of each side, on the one hand and a second comparison between the two sides in the same time.

Climatic Indicators

The climate is the first sub-indices studied; Figure 8 illustrate two comparisons regarding the six climatic indicators for the all selected countries (African countries in left or (a) and European countries in right or (b)). The form of graphs of countries in each side shows a lightweight similarity in term of climatic trends. The figure (c & d) shows the mean values of scores for each side.

Table 7. EVI classification, % of data used and total scores of the 8 selected countries extracted and compiled from the 8 selected countries

	Morocco	Algeria	Tunisia	Egypt	Spain	France	Italy	Greece
Data	96	96	94	96	96	98	98	98
Score	315	275	306	298	352	361	386	353
Class	3 Vulnerable	3 Vulnerable	3 Vulnerable	3 Vulnerable	2 Highly Vvulnerable	2 Highly Vulnerable	1 Extremely Vulnerable	2 Highly Vulnerable

Table 8. EVI SCORES, extracted from the EVI Calculator developed by SOPAC

1	Extremely vulnerable	365+
2	Highly vulnerable	315+
3	Vulnerable	265+
4	At risk	215+
5	Resilient	<215

Comparing these two sides, we see that the European side is most vulnerable on "WET" indicator and on « climate change » in general.

After Figure 8, (c) and (d), the indicators with score equal or higher than 5 are four indicators (1 for Africa side, 2 for European side and 1 is common for the two sides in same times). The Indicators which characterize the north side (European selected countries) are the "HIGH WINDS", it inform on the vulnerability to cyclones, storms, erosion… The frequent and severe wind can affect forests; fires, dry soils, and air pollution. The second important indicator is the "WET PERIODS" which indicate the vulnerability to floods and wet periods. While the "HOT PERIODS" indicators characterize the south side (North African countries) it designs the vulnerability to heat waves, desertification, water resources, temperature stress (example, near shore or shallow aquatic environments to periods of high temperatures that can affect productivity, pollution, and lead to mass mortality). On land, periods of high temperatures can also lead to interactive effects such as fires. Regarding the "SEA TEMPERATURES" indicators is common for the two sides. This indicator captures vulnerability to variability in productivity, fisheries, currents, cyclones & storms. Comparing the climate change indicators for two sides (African and European selected countries), it see that, in north africa side, the Egypt is the less vulnerable

Table 9. Aspects of Vulnerability of the MB selected countries

	Morocco	Algeria	Tunisia	Egypt	Spain	France	Italy	Greece
Hazards	3.13	2.73	3.41	3.07	3.77	3.81	4.06	3.77
Resistance	2.63	2.38	2.13	2.50	3.00	3.13	3.50	3.25
Damage	3.60	3.10	2.80	3.10	3.20	3.40	3.50	3.00

Figure 7. Comparison of aspects of vulnerability of the selected countries

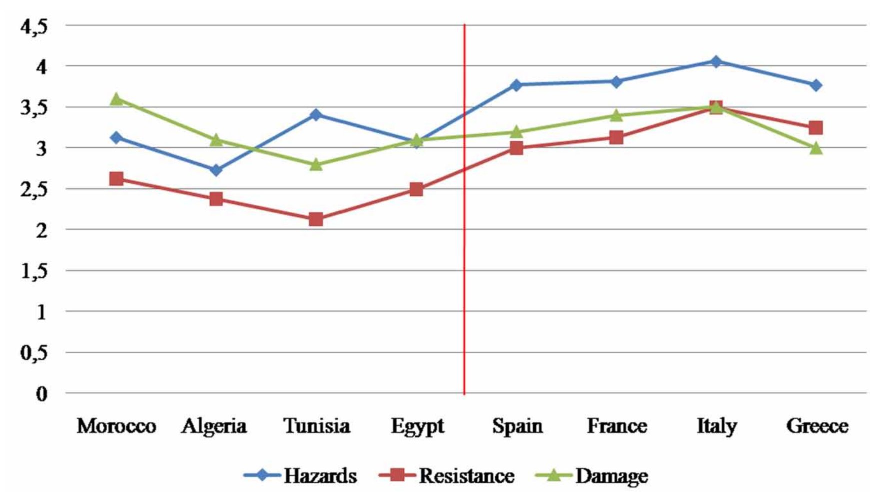
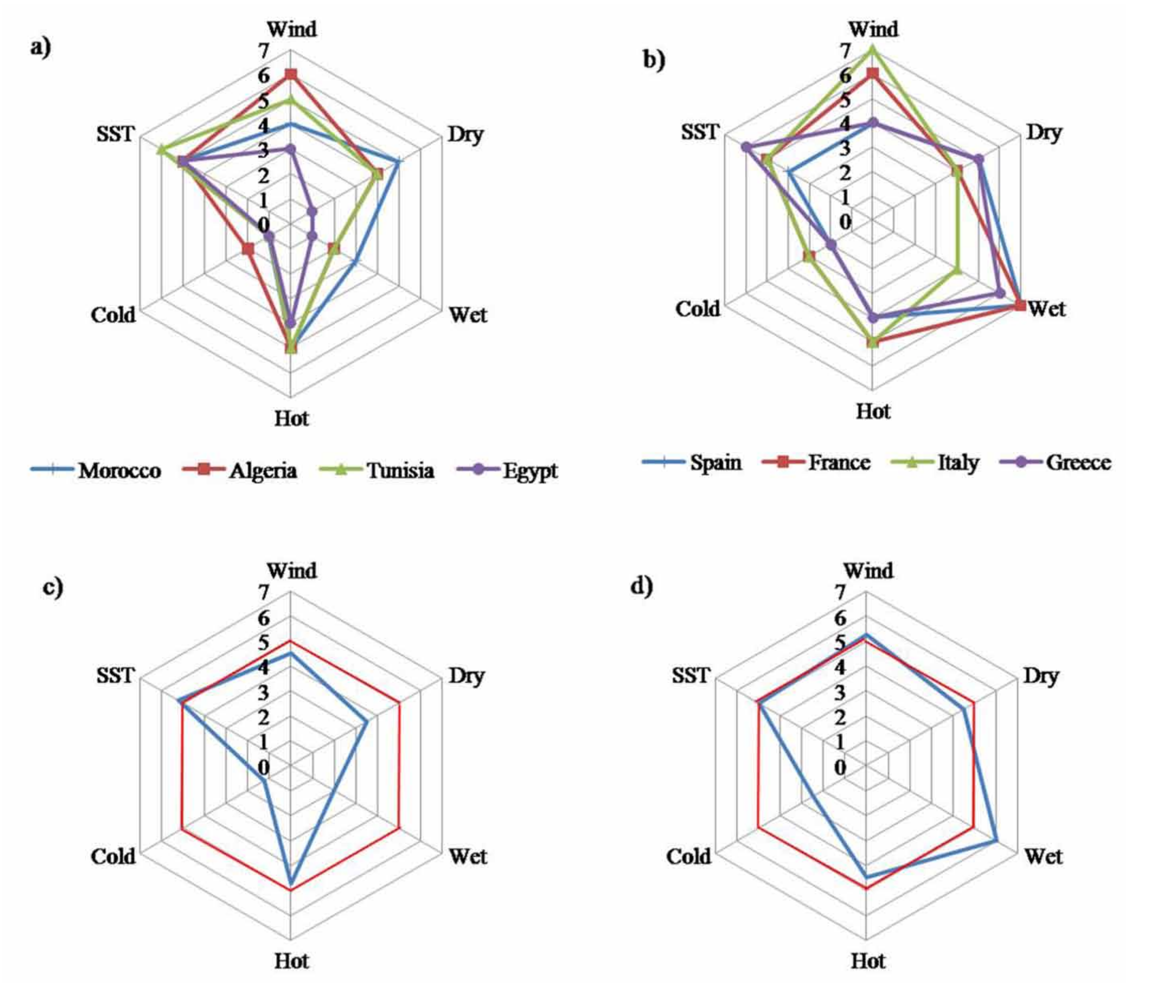


Figure 8. Comparison of climatic indicators and main values of the two sides (African and European selected countries): a) African Mediterranean countries; b) European Mediterranean countries; c) Average values of African selected countries; d) Average values of European selected countries



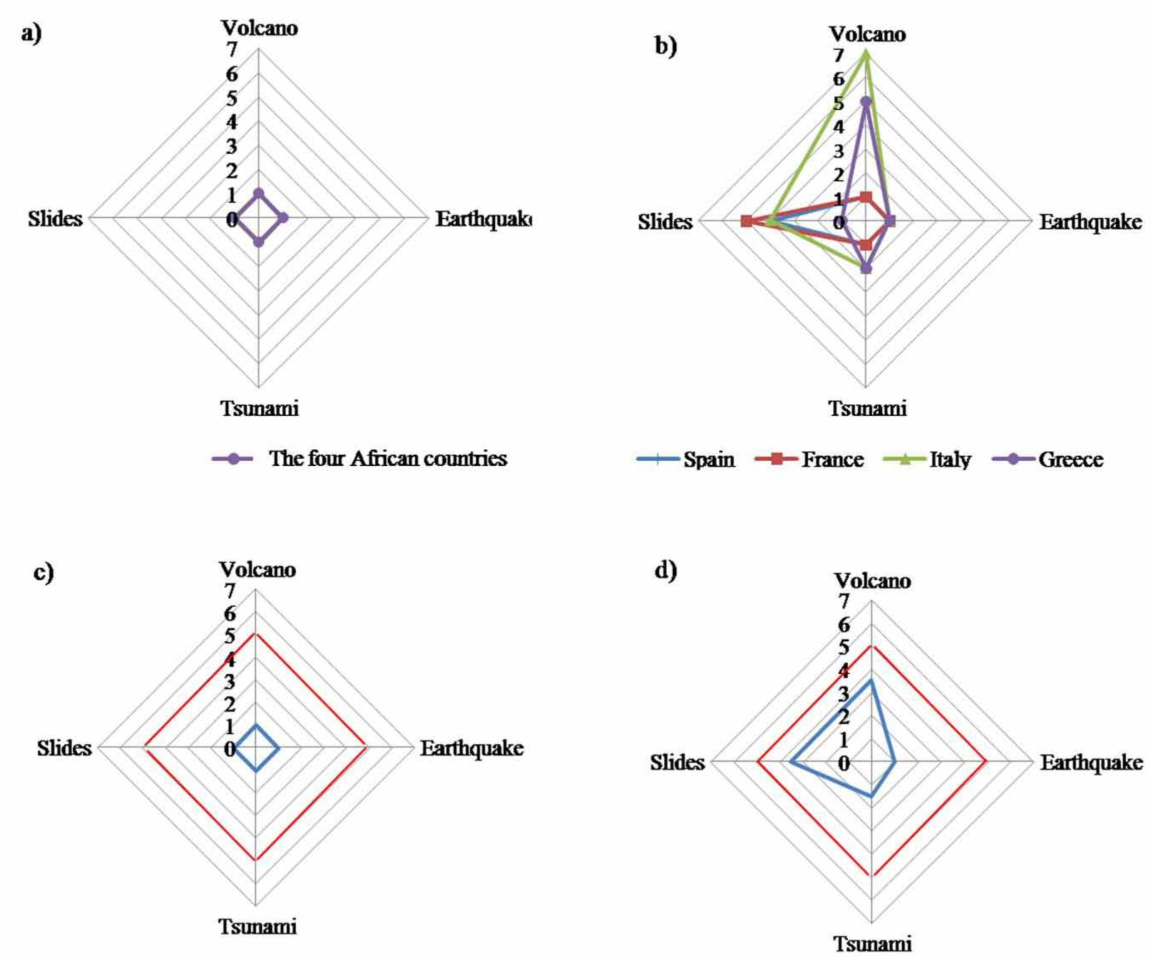
under climate change indicators, and the algeria is the most vulnearble. In South Europe, France is the most vulnerable and spain is the less vulnerable in context of climate change.

Geological Indicators

The Mediterranean is in general geologically stable, active volcanoes in the Mediterranean region are associated with active orogenic arcs, namely the Calabrian Arc and the Hellenic arc. Historical cases of devastation of entire cities, including the best-known example is the total destruction of Pompeii (Vesuvius) and adjacent cities to 79 AD, allow to think that future catastrophic eruptions are possible (AEE, 2006). The geological indicators are reported in Figure 9.

The North Africa countries are very stable on geological indicators. However the South Europe countries are vulnerable to volcanoes and slides where, France is the most vulnerable. In fact, The Mediterranean region is tectonically active and

Figure 9. Geologic indicators and main values of the two sides (African and European selected countries): a) African Mediterranean countries; b) European Mediterranean countries; c) Average values of African selected countries ; d) Average values of European selected countries



subject to frequent earthquakes, and Etna is one of the most active volcanoes in the world (Zdruli, 2011). Italy and Greece are vulnerable in term of "VOLCANOES" indicator, that captures the risk of damage to ecosystems from the physical, chemical and biological disturbances associated with volcanic eruptions (EVI, 2003). In France "SLIDES" indicator is more visible. This indicator captures the risk of habitat disturbance and persistence of ecosystems and species from catastrophic shifts in the land surface (EVI, 2003). The average values of the Figure 9 (a &b), give the results showed in Figure 11 (c &d). Comparing the two sides, we see that the European side is most vulnerable on volcanoes and slides indicator than north Africa countries and in the geology in general.

For the Major common indicators (Framed), the Figure 9, (c) & (d) shows that the two sides are generally stable, with of course relatively a geological activity in European countries.

Geographical Indicators

The geographical component has 6 indicators (Figure 10, a & b), In North Africa side, Egypt and Morocco are most vulnerable to geographic risques and the Tunisia is the less vulnerable to thsese risques. In Europan side, the Italy is the most vulnerable and Spain is the less vulnerable. For the two side, the European side is most vulnerable to geographic risque than the Africa north.

Comparing the two sides, it see that the European side is most vulnerable on "BORDERS" indicator than North Africa countries and in geographical events in general. According to the Figure 10 (c) and (d), the European selected countries are vulnerable in the "BORDERS" indicator which exceeds the limit framed in red. After the EVI calculator, these indicators captures the risk to terrestrial and aquatic ecosystems from transboundary risks including species introductions, lack of control of straddling stocks of resources, and uncontrolled migrations of humans (EVI, 2003).

Resources and Services Indicators

The resources and services category uses 28 indicators. The North African selected countries

Figure 10. Geographic indicators and main values of the two sides (African and European selected countries): a) African Mediterranean countries; b) European Mediterranean countries; c) Average values of African countries; d)Average values of European countries

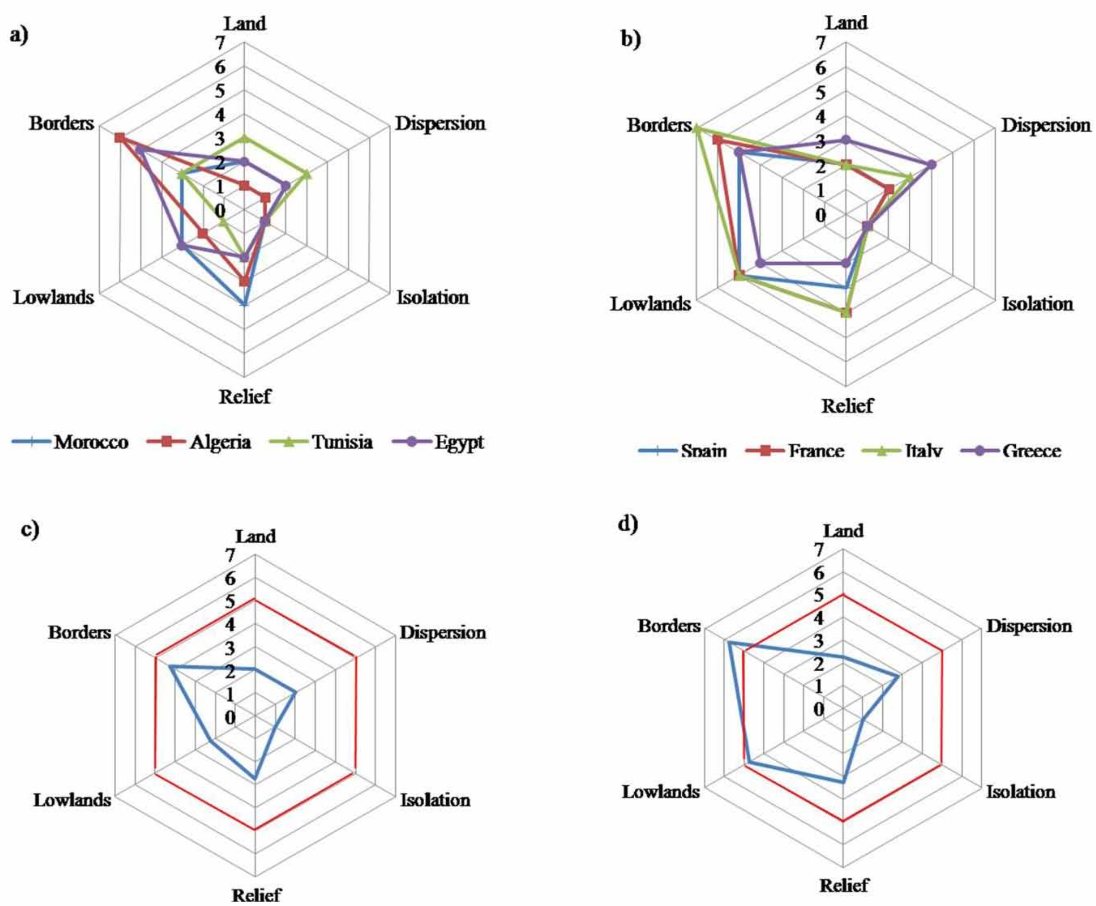
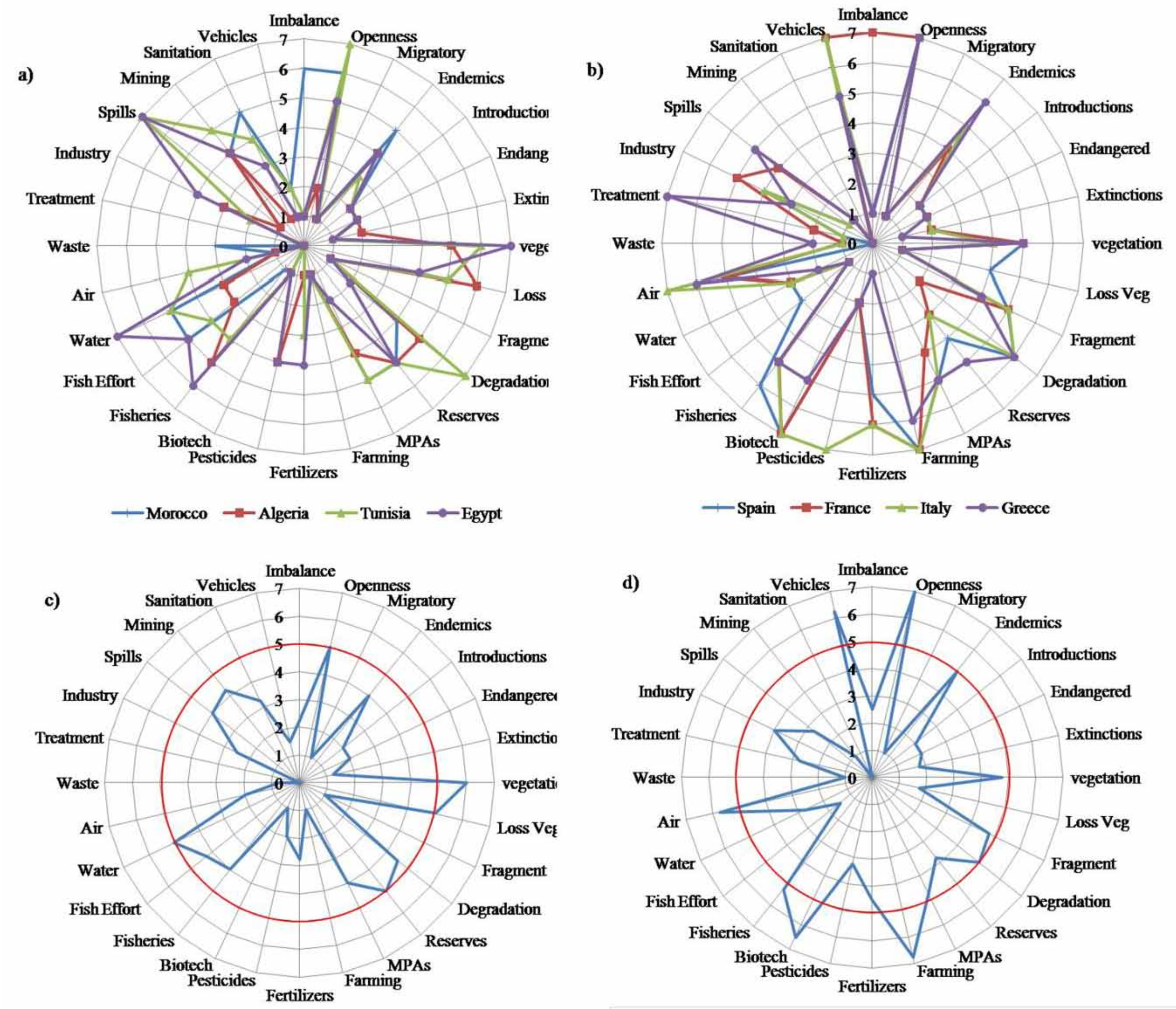


Figure 11. Resources and services indicators and main values of the African and European selected countries: a) African Mediterranean countries; b) European Mediterranean countries; c) Average values of African countries; d) Average values of European countries



(Figure 11a) are vulnerables on indicators of Openess, Endemics, vegetation & loss Veg, Water, Reserves, Degradation ; Fish effort, Fisheries, Spills and Mining. However the South European selected countries (Figure 11b) are vulnerables on Openess, Endemic, Degradation, Air, Biotech, Pesticides, Feryilizers, Farming and Vehiculs.

The average values of the Figure 11 (a & b), give the results showed in Figure 11 (c & d). The average values lead to identify 5 Major Common Indicators in Africa side and 8 in Europe side, where the indicators peak exceed the limit circled in red color. In African selected countries, the most important indicators are the following: the first indicator is "VEGATATION" or natural vegetation cover remaining. This indicator focuses on the loss of natural vegetation cover with implied impacts on biodiversity (EVI, 2003). The second is the "LOS VEG" or rate of loss of natural vegetation cover, which measures the rate of loss or gain of natural vegetation cover in countries (EVI Calculator). It focuses on biodiversity, ecosystem resilience, prevention of soil loss, reduction of runoff, and soil formation. The third is the "RESERVES" or Terrestrial Reserves. After the same EVI Calculator, this indicator focuses on areas with the most intact terrestrial environments and the level of environmental management. And the last is the "WATER" Indicator or renewable water. This indicator captures the risk to aquatic ecosystems and ground waters from over-extraction of freshwater resources (EVI Calculator). It focuses on sustainable use of surface water and groundwater and damage through salinization, and damage to rivers, lakes and other habitats. In term of water, around the Mediterranean Sea, alluvial plains are few; the Nile Delta is the largest. The coastal lowlands are particularly vulnerable to climate change, which can affect hydrology (UNEP/MAP/MED POL, 2005). Agricultural irrigation and population growth are also reducing the flow of fresh water in the rivers that feed the Mediterranean's alluvial plains (L'Europe et al. 2014). Estimates by Blue Plan conclude that by the year 2025, eight of the twelve southern and eastern Mediterranean countries could be consuming more than the total of their renewable water sources (UNEP/MAP/MED POL, 2005). Already, all major rivers flowing into the Mediterranean have had much of their flows diverted to agriculture and other uses over the past 40 years, resulting in a 20% reduction in freshwater inflow into the Mediterranean (Ludwig et al, 2009). Regarding the European side, after the results, their countries are in general vulnerable in the indicators of over exploitation of biodiversity, specially, the following indicators: Firstly, "ENDEMICS" indicator or endemic species describe the risk of losing unique species. Losses of key species can affect ecosystems and potential for sustainable activities. In fact, the state of biodiversity reflects the cumulative effects of the pressures affecting the Mediterranean coastal and marine environment (UNEP/MAP, 2015). Although diversity is still high in the Mediterranean; the number of species of reptiles, marine mammals, birds and fish are falling dangerously (UNEP/MAP 2012). The Mediterranean also offers a wide range of habitats from commercial, ecological and cultural importance. Secondly the region is vulnerable to the "DEGRADATION" indicator. This indicator captures the status of loss of ecosystems in a country. Types of degradation include water, agriculture, deforestation and grazing. These can be associated with salinisation and desertification. This indicator highlights the breakdown of ecosystems which leads mainly to decreasing biodiversity. The overuse beyond the limits of sustainability affects many exploited stocks of Mediterranean fish. These results in changes in species diversity, some species being considered as threatened. Overuse has also led to changes in community structure, trophic network; thirdly, the "FARMING" or intensive farming. This indicator captures the risk of pollution, eutrophication, ecosystem loss and the risk of diseases (EVI Calculator). It focuses on lands used for intensive agriculture, including the farming of poultry, aquaculture, and some farming of animals were kept in feed lots. Intensive farming usually involves use of pesticides and a concentrated production of wastes, and fertilizers. The Table 10 shows the fertilizer consumption of arable land (Kilograms per hectare), in 2008.

The consumption is largely different between African and European selected countries, where in general, the quantity used in European countries are very important than in African countries with a

Table 10. Fertilizer use and nitrogen release in the Mediterranean region. Source: extracted from a map made by UNEP Mediterranean Action Plan (MAP)/MED POL; World Bank online database

	Africa	Europe
Fertilizer consumption Kilograms per hectare	Algeria and Tunisia 6 to 50 Morocco 50 to 100 and Egypt 724	Spain, France, Italy and Greece 100 to 200

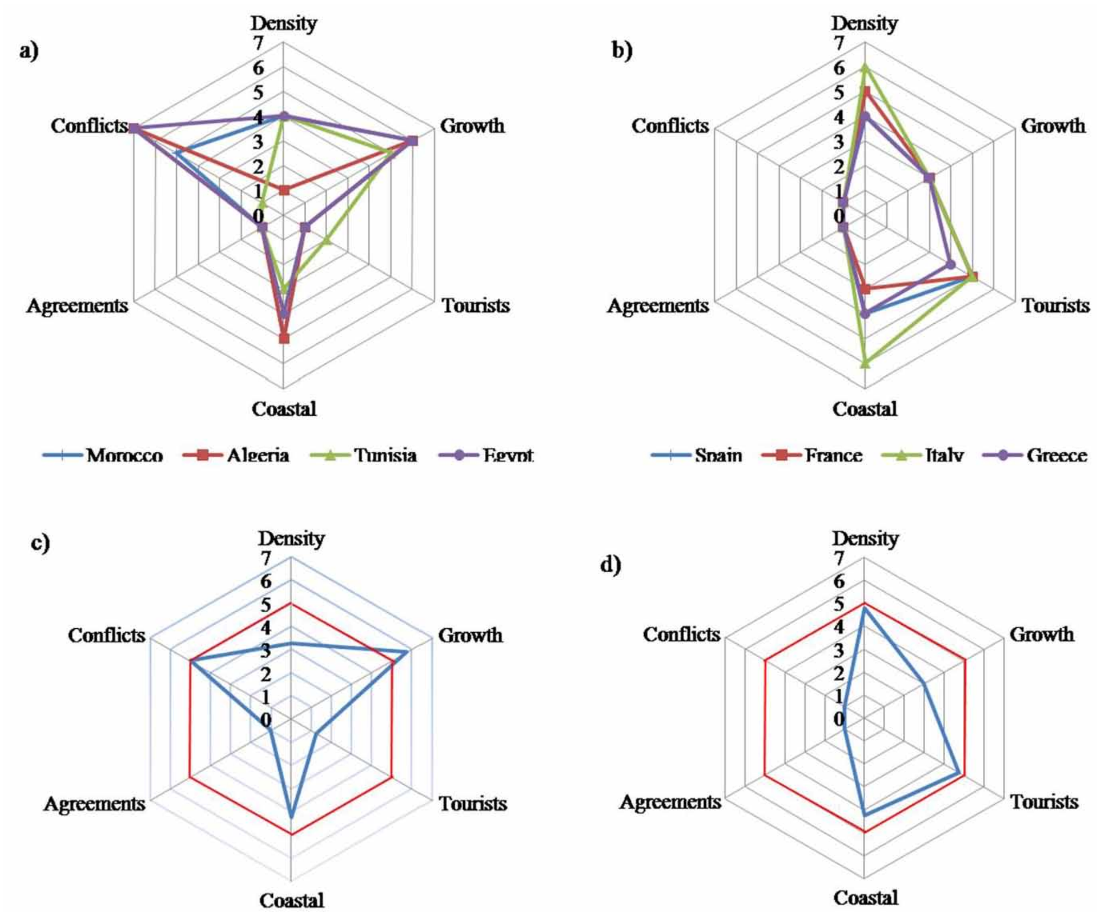
high level fertilizer consumption in Egypt. That is due to the economic power of the European countries and the high hydraulic capacity of the Nile in Egypt. In term of the "BIOTECH" indicator or biotechnology, the European selected countries are very vulnerable. This indicator captures the genetic pollution and unpredictable ecosystem effects of introducing incompletely tested bioengineered organisms (SOPAC, 2004). This includes new toxin-producing organisms and terminators. The "FISHERIES" indicator or productivity overfishing captures the risk of damage to fisheries by examining rates of extraction. If, the catch is high and productivity low, there is a higher risk that overall fisheries stocks can be depleted than if the converse were the case. Methods of destructive fishing constitute other pressures related to the intensive fishing activity in the Mediterranean. Indeed intensive fishing has very marked effects at all levels of biological organization of marine life, namely the population, community and ecosystem (AEE, 2006). Another aspect of vulnerability is dependent to air pollution particularly the "AIR and "VEHICULES" indicators. The first is "AIR" or Sulphur dioxide emissions. This indicator captures the risk to ecosystem health from air pollution, including its effects. High rates of emissions of gases from industry present risks to all aspects of the environment. The second indicator is the "VEHICLES"; it captures the risk to terrestrial ecosystems in the form of habitat damage, habitat fragmentation, loss of biodiversity, pollution and industries (SOPAC, 2004). Regarding the "OPENNESS" or Environmental Openness is the common indicator both for the African and European selected countries. After the same report of SOPAC (2004), this indicator captures the risk of damage to a country through the importation of foreign materials (physical, chemical and biological) by land, air or sea. Understanding how these multiple pressures reduce the limits of sustainable catch is necessary to efficient management, which is crucial in a region of the world in which seafood are culturally and economically vital (UNEP/MAP 2012). The situation of desertification in the Mediterranean is at best *incomplete*. 30% of semiarid Mediterranean drylands are affected by desertification (Rubio & Recatala, 2006) and that 47% of the region's people suffer these effects (Safriel, 2009). In addition of desertification, water scarcity and land degradation are factors which have negative consequences both on ecosystem and on people. The decrease of available resources and the social/political instability are the consequences of a degraded environment.

Anthropogenic Indicators

The population of the North Africa's countries is young, growing rapidly especially in coastal area, but the population of south Europe's selected countries is concentrated more and more in urban areas. The Figure 12 (a & b) shows the anthropogenic category that gathers the 6 vulnerability indicators as mentioned above.

The average values of the Figure 12 (a & b), give the results showed in Figure 12 (c & d). In African selected countries, the most important indicators are the following: "GROWTH" and "CONFLICTS" indicators. The first is human population growth or potential for future damage caused by all human activities. This indicator focuses on the potential for damage relating to expanding human populations. It signals increasing rates of habitat damage and exploitation of natural resources; the second is the HUMAN CONFLICTS. Conflicts can occur in habitat degradation, pollution and absence in environmental management. The direct effects include degradation through bombing chemicals used, and damage caused by displaced people under emergency conditions (EVI Calculator). The impact of poverty, unequal distribution of wealth and land, unemployment and epidemics, etc, accelerated by climate change will increases the risk of conflict. In addition, the Sea level rise threatens the living conditions of population living on the Mediterranean coast. Especially in African selected countries,

Figure 12. Anthropogenic indicators and main values of the African and European selected countries: a) African Mediterranean countries; b) European Mediterranean countries; c) ES of African Mediterranean Average; d) ES of European Mediterranean Average



the important economic sectors like tourism and agriculture depend heavily on weather conditions, and the increase in temperature water scarcity is likely to become more severe in the future and a major cause of regional conflicts (Osberghaus & Baccianti, 2013). Regarding the European side, is especially vulnerable to the "DENSITY" indicator or human population density. The rising number of population increases pressure on the environment for resources, for the attenuation of wastes and physical disturbance of the environment. And the "TOURISTS" indicator shows the impacts associated with international visitors which place additional pressure on the environment (overuse of local resources and pollution).

Major Common Indicators of the Mediterranean Basin

The urgent actions began from identify major areas of intervention, from removing barriers to private adaptation to the fostering of international cooperation.

Anthropogenic factors such as tourism and urban development, lead to fragmentation, degradation and loss of habitats and landscapes. The Mediterranean region remains valuable and valued, but also a region threatened. Determining common factors allows to accurately assessing the state of the environment on the conditions and trends of each side (African and European selected countries). This section recommends that future research should address the causal relationships to support the implementation of management measures and systematically addresses the full range of pressures that human activities have on the environment Mediterranean basin. The most critical issues affecting the Mediterranean environment are illustrated in table 11. It can be clearly seen that Mediterranean basin is vulnerable to extremely vulnerable area. From the result of EVI, it showed that 9 of 50 are common in North Africa and 14 of 50 in south Europe. The called MCI represent the overall vulnerability of the region that reach the score equal or higher than 5.

From Table 10, the countries of the southern Mediterranean appear more vulnerable for indicators ("SST" and "HOT" for the climate category and "OPENESS", "VEGETATION", "LOS VEG", "RESERVES" and "WATER" in terms of resources & services and "GROWTH" and "CONFLICTS" for the anthropogenic category). Indeed, they are both more exposed to accelerated desertification, increasing scarcity of water resources and on the other, they are provided with economic structures that rely more heavily on resources natural as well as more limited technical and financial capacity to implement large-scale adaptation options. The water shortage is acute in African countries, justifying the use of alternative water resources, such as wastewater reuse and desalination. Regarding the countries of southern Europe, they are more vulnerable to the indicators ("WIND" and "WET" for the climate sub-indices and the indicators "OPENESS", "ENDEMICS", "DEGRADATION", "FARMING", "BIOTECH", "FISHERIES", "AIR" and "VEHICULES" for the resources and services sub-indices, "DENSITY" and "TOURISTS" for anthropogenic category). For the common indicators of the two sides European and African in same time, it sees that this region is vulnerable in "SST" and "OPENNESS" indicators. In fact, these indicators connect the socio-ecological systems of the African and European countries. The results show that the EVI scores of the selected countries is between 275 in Algeria and 386 in Italy, which class the Mediterranean basin as vulnerable to extremely vulnerable area to climate change and anthropogenic impacts as mentioned in Table 6. We note that the rate of "population growth" and "conflicts" indicators in African Mediterranean selected countries are very high and "population density" and "tourist" indicators in European selected countries indicates a high vulnerability. These anthropogenic indicators exert perceptible pressure on the Mediterranean environment. To reduce the overall vulnerability, all MCI must become management priorities. From the above results, the socioeconomic and environmental impacts of CC in the Mediterranean area are focused on the following areas:

1. Water and soil quality;
2. Biodiversity and reserves;
3. Agriculture and fisheries;
4. Sea and coastal;

Table 11. Mean values of the two sides (African and European selected countries)

	Major Common Indicators				
	Climate	**Geology**	**Geography**	**Resources and Services**	**Anthropogenic**
Africa	SST HOT			Openess, vegetation Los veg, reserves, water	Growth Conflicts
Europe	SST WIND WET		Borders	Openess, endemics Degradation, farming Biotech, fisheries, air Vehicules	Density Tourists

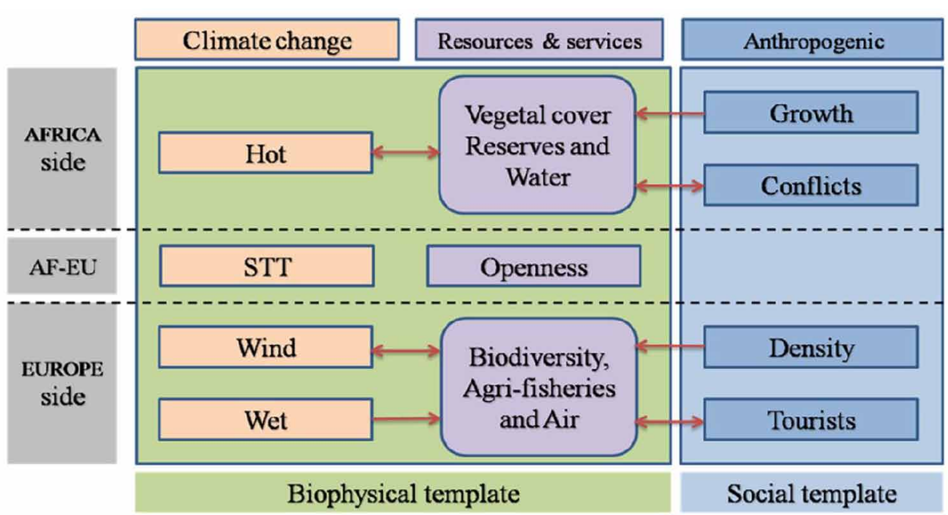
After the above mentioned list of Major Common Indicators, it sees that these trends regarding the state of the environment are related to human impacts, like urbanization, tourism, conflicts, economic (agriculture) and industrial activities, sea navigation boating and fishing, etc. In term of economic sectors, in the northern countries, the trend is towards agricultural practices to maximize yields per hectare through specialization and intensification, this resulting in increased consumption of fertilizers and pesticides. The alternative to this trend, organic farming has developed since the 70s so heterogeneous and mainly in Italy (PNUE/PAM-Plan Bleu, 2009). Respecting the marine resources, the degradation of the marine food chain fishing and changes in the structure of fish populations has a negative impact on the entire ecosystem as already explained. Regarding the population growth and density, the coastal zone is the most affected, in the Mediterranean region, leading to loss of biodiversity due to the destruction of habitats. Problems related to "concrete" coastal meet throughout the Mediterranean. Uncontrolled development - particularly the tourism infrastructure - is usually the cause. The most important example is the impact of the FADESA project on the Moulouya wetlands at the extreme north-eastern of Morocco (Mediterranean side). In the context of the implementation a large tourism development plan launched by Morocco (Plan Azur), a building complex has been implemented by the Company FADESA at the western limit of the town of Saidia. The complex, adjacent to the mouth of the Moulouya, which is registered in Ramsar List in January 15, 2005 under No. 1478, was of great ecological wealth. A Ramsar Advisory Mission made by Triplet *et al*, (2010), demonstrates that the development of the tourist complex adjacent caused or accelerated a series of events and behaviors that led to a significant loss of biodiversity. In addition, the same report notes the absence of any countervailing measure to these values and the virtual absence of dialogue between the actors involved in environmental protection and responsible tourism complex. Effectively, the tourism sector is both an economic asset and also a negative impact factor. In fact, tourism is an important economic activity for all countries bordering the Mediterranean Sea. With their position at the crossroads of three continents, they attract 30% of the world's international tourism. In 2007, they hosted about 275 million international tourists (PNUE/PAM-Plan Bleu, 2009), and generating more than a quarter of international tourism receipts (190 out of 738 billion Euro worldwide) (UNEP/MAP 2012). It is forecasted that the Mediterranean region will reach 500 million of international tourist arrivals by 2030 (UNWTO, 2012). The bulk of the tourists are of European origin (81,1% in 2010) followed by Middle East tourists (6,4%) that recently have outnumbered those coming from the Americas (5,7%) (UNEP/MAP/MED POL, 2005). Still, tourism in the Mediterranean Basin is strongly coastal, with more than half of all visitors (and as high as 90% of visitors to some countries) visiting coastal areas. Tourism is heavily seasonal, peaking in July and August (PNUE/PAM, 2012). Tourism contributes CO_2 emissions, mostly through increased use of air and road transportation (UNEP/MAP, 2012). These activities cause several types of pollution, which translates into a high vulnerability in the indicators of "AIR" & "VEHICULES". The Mediterranean coast is home to many human activities that are significant causes of degradation like pollution: the first form is the wastewater. The efficiency of installations or wastewater treatment plants to remove pollutants is often quite low. The problem is compounded because of the rapid growth of coastal urbanization, particularly on the southern shore of the Mediterranean. Solid waste is often disposed in landfills, generally after no treatment. Another form of pollution related to the agriculture sector mainly by pesticides, fertilizers and genetic. Most coastal areas of the Mediterranean are home to industries that produce industrial waste such as heavy metals and persistent organic pollutants (POPs) that may affect all forms of life in the Mediterranean. The POPs are considered as a major source of contamination of the sea. On the other, maritime transport is a major source of pollution of the Mediterranean Sea by crude oil. With regard to of soil quality and desertification especially in the countries of North Africa, sand erosion can have a multitude of effects on coastal ecosystems: destruction of surface soil resulting in pollution of the groundwater, degradation of dune system resulting in decreased sediment resources, desertification and loss of biological diversity (UNEP-EEA, E. E. A, 2006). As mentioned above, the Mediterranean region knows some geologic activities. The social and economic effects of large earthquakes can be devastating, especially in coastal urban areas. Increased seismicity and tsunami activity create the need for better coastal protection (UNEP-EEA, E. E. A, 2006). Some of factors need to be well managed like water resource, protected area (reserves), loss of forestation, tourist accommodation, waste water and solid waste. To reduce the Mediterranean environmental vulnerability and reach the sustainable development, all of factors must restrict implementation.

General Scheme of Mediterranean Vulnerability Basing on the Major Common Indicators

Climate change causes many environmental impacts, which disrupts the well-being of man. The Mediterranean has always been an area of intense human activity. Incomes in the region are largely from the sea. Mediterranean is a relatively small enclosed sea, who knows a wide variety of sensitive ecosystems. Considering the political complexity of the region, management of the Mediterranean environment requires multilateral environmental agreements, in favor of sustainable development of all bordering nations. Basing on the outputs of the EVI tool, we develop a scheme (Figure 13) which gathers the principal factors (or indicators), influencing environmental vulnerability and traces also the interactions of the different components of Mediterranean vulnerability.

The chapter illustrates that although a comparison of vulnerability concerning, different topics, it will help to make out vulnerable areas and use this as an input to the designing of project alternatives.

Figure 13. Scheme of the principal factors, influencing environmental vulnerability and interactions of the different components of Mediterranean vulnerability

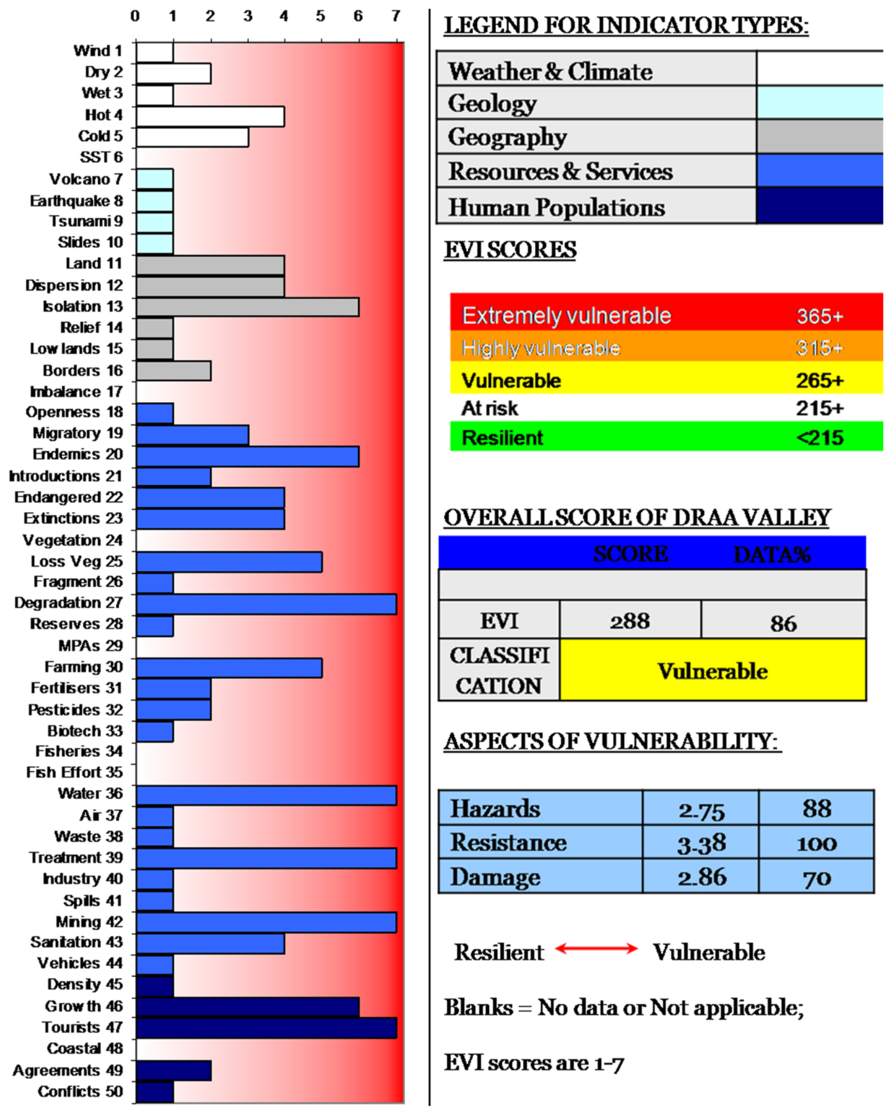


The impacts of climate events that occurred in the Mediterranean basin, such as heat waves, floods and forest fires, highlight the significant vulnerability and exposure of certain ecosystems and human systems. The impacts of these climatic events include the alteration of ecosystems and impact on human well-being. These impacts are consecutive significant lack of preparedness to cope with climate variability in some socio-economic sectors. Climate-related hazards accelerate other stress factors, often with negative effects on livelihoods, for people living in poverty (IPCC, 2014) especially for the African selected countries (AMC). In addition, conflicts especially in AMC accelerate vulnerability to climate change and harming also infrastructure and natural resources. To analyze the various environmental issues that affect the Mediterranean environment, it is necessary to know the natural characteristics of the Mediterranean and to have an overview of the main factors affecting the region. Use this information to better understand the interactions between Mediterranean ecosystems and human factors were aimed at allowing all Mediterranean countries to cooperate. The cooperation can addressing common challenges they face in terms of environmental degradation. In order to have a more complete vision of the situation and perhaps a somewhat different vision, the responses to environmental change are multidimensional. They require changes in hunting, fishing, economic activities and lifestyle. By integrating indigenous knowledge into scientific research and taking into account their distinct culture in the development of possible solutions.

Analysis of the Applicability of the Environmental Vulnerability Index at Local Scale: The Sub-Catchment of Middle Draa Valley

Therefore, measures to adapt to climate change should be a priority for national governments in the area, and also at local scale (for example at catchment or sub-catchment scale). Indeed, the intervention in selected catchments is needed to reduce the environmental vulnerability of a country with a high score. In this part of the chapter, we address the main policy relevant questions about vulnerability indicators and adaptation and provide answers based on a vulnerability index applied to the case of 8 Mediterranean countries. Downscaling could be a key step for adaptation for the most vulnerable countries wishing to reduce their vulnerability scores. To identify the most effective interventions in the most vulnerable to a wide sub-basin area in 2014, Karmaoui *et al* (2014) has made an application of the same index on a sub-basin of the Draa valley, upon evaluation of an environment of the Sahara region. This assessment identified stabilization activities with a positive environmental impact on the areas and indicators showing great vulnerability. The evaluation identifies the most vulnerable sectors of given area and what is the degree of vulnerability of the population. The study also helps to identify risks that could prevent the environment to provide goods and services; and preventive measures that can be taken to improve the environmental situation and reduce the negative impact of human action on the environment. For this, we discuss an example of implementation of the environmental vulnerability index in Draa Oasis. This region is part of the Biosphere Reserve of Southern Moroccan Oases, located in southeastern Morocco. It occupies approximately 15000 km^2. The climate of the region is arid; the rainfall is an average of 80 mm per year. Evaporation and the daily and seasonal thermal difference are high. The region has a rich biodiversity. This area is experiencing a state of degradation, exacerbated by the effects of climate change that prefigure a considerable acceleration of desertification as a corollary with abandonment and loss of productive ecosystems whose ecological and social economic role remains for major regions of the southern Morocco. The Figure 14 gives the profile of environmental vulnerability of this oasean zone.

Figure 14. Environmental vulnerability Index (EVI) scores for Draa valley
Source: (Karmaoui et al, 2014)



From this profile and the above information, we can note the following points regarding the applicability of environmental vulnerability index:

- The EVI is flexible for comparative purposes, and applied to any scale sufficiently;
- Helps to identify issues of vulnerability, risk types and approaches to environmental management by region;
- The vulnerability index can be used to capture the change by recalculating it every 5 years like mentioned in the EVI report (EVI, 2003);
- Improving the awareness of society in future to CC;
- Identify priority sectors for urgent actions;
- Data collection and vulnerabilities can be managed locally;

- There is a need to streamline the collection and improve the quality of data on the environment in general.

Development and Implementation of Policies

The role of the policy is to contribute to sustainable development through coordinated regional measures to respond to the environmental vulnerability. The policy can be guided by the Major Common Indicators (MCI) identified in the previous sections of this chapter. These include policies in environment, water, land, forestry, energy, transport and agriculture among others. Mediterranean countries must prepare and implement policies to address environmental vulnerability on both adaptation and mitigation activities. The MCI prioritize priority activities to enhance adaptation capacities. There is a need to encourage implementation of national and regional adaptation, by adopting the various international conventions of environment and protocols already prepared, in particular:

- The Convention on Biological Diversity (CBD);
- The United Nations Framework Convention on Climate Change (UNFCCC);
- The United Nations Convention to Combat Desertification (UNCCD);
- The Convention on International Trade in Endangered Species (CITIES);

In Africa countries, the Policy must be based on the following priorities: climate (Hot), vegetation; water and on population growth and conflicts by promote and implement research and observations including monitoring and prediction. The dependence on rain-fed agriculture in the North African countries implies that primary production is highly vulnerable to climate change. In addition, the increasing temperatures ('Hot' indicator) leading to adverse impacts to socio-economic and ecological. The impacts include: loss vegetation leading a declining crops yields and increasing food insecurity, reduced water resource, declining levels of water resources, and natural resource accelerated by the high rate of population growth and spread conflicts. These findings lead to engage a cooperative approach to responding to these factors. The policy, thus, represents the commitment of the selected countries in cooperating in the efforts to address the challenges of climate change by guiding coordination on water resources, and food security, energy, and ecosystem services, soil protection, education and training. The major causes of the vegetation loss include clearing for agriculture and settlement, overgrazing, wildfires, and over-exploitation of wood resources. These activities contribute to the increase of carbon dioxide. The overdependence of these countries on forest resources is due to lack of alternative and technologies for energy and agricultural production. Management strategies may include the restoration and the good governance of the degraded wetlands and the promotion of the alternative energy sources (renewable energy especially solar energy).

Regarding the European countries, the Policy must be based on the following priorities: Biodiversity, agriculture, tourists and air. In fact, the biodiversity forms an important source of food and income. Change in ecological systems like, destruction of habitats, fires, will lead to disappearance of some species. With a vast land area covered by forests as well as important biodiversity, European southern countries are considered to be one of the premier tourism destinations in the world. The region has beautiful natural and a rich diversity of scenery, hence the importance of the need to maintain or increase of biodiversity and other tourist attraction. The air pollution is another challenge that faces these countries. The use of motorized means of transport especially in the urban area is on the increase as the economies of the region grow. To reduce greenhouse emissions from the transport and industrial sectors, these countries shall develop policies to reduce these emissions. Otherwise, the agricultural sector plays a fundamental role in improving economic growth. Whereas, the intensification of agriculture presses the soil and the forestry resources it also contributes to natural carbon sinks. There needs to having environmentally friendly and efficient livestock and crop production systems.

The Chapter Recommendations

We must conclude that the root causes of environmental vulnerability in the countries of North Africa are rapid population growth and unplanned urbanization and conflicts. The deterioration of the living conditions of the population and increasing human insecurity due to conflicts within and between states (Pomerleau, 2009) exacerbate the climate change impacts and its consequences on human societies. With regard to of trends in the agricultural sector in Africa, certainly impacts of climate change on the human wellbeing will be multiple. For example, agricultural production will be severely compromised by climate variability and change, the areas of arable land, and yield per hectare are likely to decline. (Pomerleau, 2009) The most important recommendations are long-term actions that are beyond the traditional field of soil conservation and biodiversity. Prospects for reducing vulnerability are very limited in the absence of economic development. In the long term, it is imperative to generate large number jobs. This could be facilitated, for example, promote trade policy to support the industry and also the export of high commercial value. An environmental management plan must incorporate socio-economic parameters and adopt measures based on indicators of vulnerability in the region. Given its hot climate constraints, the African countries must develop non-agricultural economic drivers, and a suitable education system that supplies the companies with qualified personnel. With regard to access to safe drinking water, rising temperatures and the spread of deserts most likely exacerbate shortages. Moreover, changes in runoff and melting glaciers caused by global warming will add to ecological stress, compromising the availability of water for irrigation and human settlements (Watkins, 2008). For the countries of southern Europe, the most fundamental challenge for these countries may lie in the way of thinking about economic progress taking into account the stability and ecological balance. The diagnosis of the state of the environment of European countries based on the EVI index highlighted endangered areas by land-based activities (that is to say pollution from the urbanization, agriculture and industrial activities, density of population, and tourism. In addition, the unsustainable fishing practices, which can lead to overexploitation of living resources and have an impact on the marine environment; natural hazards, especially floods, volcanoes and sea vulnerability have also been added to the list of emerging issues.

To finish, this chapter does not provide an overall status of the Mediterranean environment, but it details some of the emerging problems of the region. The African countries should follow the European model for economic development. However, the European countries must question the African experience in the fight against land and soil degradation. In terms of the applicability of the Environmental Vulnerability Index, an analysis of the vulnerability of major watersheds used to conduct interventions in high priority watersheds. In general, priority should be given to high-risk areas. An evaluation strategy in priority watersheds should be one element of a multi-sector long-term strategy. The watershed management, disaster awareness, management of forests, urban planning, the use of biomass for energy, could reduce the vulnerability of sub-basins and subsequently for the most vulnerable countries. These, can help to develop strategies for watersheds and nationally and identify interventions producing a large-scale impact. To ensure that the best decisions are made based on the best available data, it must measuring changes occurring in ecosystems using various indicators. For this purpose, it is necessary to have data storage in the form of databases. This chapter could be used to highlight the policy options to develop priority actions in order to protect the Mediterranean environment.

CONCLUSION

The chapter aims to determine the state of the Mediterranean environment to support decision making based on science. The approach is based on environmental vulnerability assessment at regional scale. The cluster analysis resulted in several factors of vulnerability including water stress, soil degradation, and vegetation loss. The area around the Mediterranean Sea extends over three continents: Europe and its southern peninsulas in North, Asia South-west to the east, and North Africa. Overall, it is a very populated area, with a complex political history; today, 21 countries, ranging in size from 2 to 2,4 million square kilometers, bordering the Mediterranean Sea. 8 countries were selected, 4 in the African north side and 4 in south European side. These countries are connected by the Mediterranean, which is a closed sea, or much of the economic activity in these countries is concentrated on the coast and in the sea. This area is characterized by a diverse religious, political, ethnic, landscape and biodiversity. The ecological balance and socio-political stability in the region involve multilateral cooperation between countries of the same side and cooperation between the two sides (bilateral cooperation). To be constrictive such cooperation should be based on an understanding of the environment of the region. To analyze the various environmental issues affecting the region, it is necessary to know the indicators of environmental vulnerability affecting the region and use this information to better understand the interrelationship of the socio-ecological system. In this context, we used the results of the vulnerability index that is widely recognized in the scientific community.

According to the results of this comparative analysis of the environmental vulnerability, we identified indicators, called Major Common Indicators. In the North African part, indicators are common in the field of the quality of water and soil related to the desertification. In fact, the desertification exacerbates poverty and negatively affects social order and stability (Kepner, 2006). It can contribute significantly to water scarcity, internal displacement of people, migration, and social breakdown and thus presents a recipe for political, social, and economic instability which can also lead to tens between neighboring countries and armed conflict (Kepner, 2006). Progress has been made in recent years for the protection of ecosystems, significant efforts are still needed to anticipate the effects of climate change, managing natural resources such as scarce water and energy, and preserve areas biodiversity, promote and production patterns more sustainable consumption. The lack of reliable information comparable over time and space to show the reality of the pressures on the environment, their environmental condition, the effects of the responses given the stakes, undoubtedly handicap analysis or description of trends. Climate change is seen as a potential threat to the development or security, states with the most reduced to cope as the countries of northern Africa adaptability. This analysis may strengthen the exchange of information on developments in the environmental field, to improve the effectiveness of the measures implemented. The main problems of the African selected countries consist of soil and vegetal degradation, inappropriate water management due to the population growth and conflicts. As opposed to the European selected countries, where, efforts should be made to overcome the problems posed by the biodiversity loss, agriculture and fisheries vulnerability, and the use of chemicals and their impacts on the environment. The European countries are most industrialized; there are a priori mechanisms necessary preventive and corrective. In the African countries, there are lacks of political desire to enforce environmental regulations. It's growing at the expense of the environment because it does not have the economic conditions or the required technologies. Ratification of the protocols remains a challenge for the region, because most existing multilateral environmental agreements have a limited number of ratifications.

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KEY TERMS AND DEFINITIONS

Anthropogenic: Resulting from or produced by human beings.

Climate: Is the distribution of the conditions of the atmosphere in a certain area for a specified period.

Climate Change: Is the changes in climate over time due to natural changes or caused by human activity, affecting the composition of the global atmosphere.

Disaster: A serious disruption of the functioning of a society causing losses in term of economic, environmental impacts and human, that goes beyond the ability to cope.

EVI: Is a numerical index leading the assessment of the environmental stat of a country or a region.

Indicator: is a marker for monitoring progress towards desired goals.

Resilience: The capacity for self-organization, and to adapt to impact factors.

ENDNOTES

1 CIBRA: http://www-3.unipv.it/cibra/edu_Mediterraneo_uk.html

Chapter 7
Vulnerability to Local Climate Change:
Farmers' Perceptions on Trends in Western Odisha, India[1]

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ABSTRACT

The paper analyses the perceptions of the farmers on various aspects of present as well as future vulnerability to local climate change in western Odisha, India. The changes in various climatic factors like rainfall, temperature, drought frequency and intensity during last three decades have been assessed. The farmers' experiences on hardships faced, natural and human induced causes of the changes observed have been examined. The perceptions on changes/trend in various vulnerability factors such as water availability, soil quality, early warning system, deforestation, social safety nets, institutional support system, degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species etc. have been scrutinized. Besides, the future vulnerability to climate change has been assessed by ranking the vulnerability factors (economic/environmental/social/institutional) with respect to their effects during past, present and future climatic risks in the matrix form, thereby identifying the vulnerability factors posing greater threat in future. The study is based on the survey of 139 households. The study finds significant changes in behavior of climatic factors in western Odisha. The factors that are posing greater threat in future are increasing temperature and rainfall variability, frequent pest attack and plant diseases, gradual decline in grazing land and fodder availability, reduction and degradation of wild life habitat and loss of wetland and water bodies.

1. INTRODUCTION

Climate change is unequivocal, accelerating and beginning to affect vulnerable states. The complex process of climate change affects the vulnerable populations, livelihoods and different sectors through increasing occurrence of climate induced natural disasters (CINDs) like drought, flood, cyclone, desertification, and global warming (IPCC 2001). The consequent situations are further ag-

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gravated by human actions or inactions. Among these CINDs, drought is considered by many to be the most complex but least understood affecting more people than any other hazard (Hagman 1984, IPCC, 2007). More than half of the world population is susceptible to drought every year (Kogan 1997). It is a slow onset creeping disaster which is gradually increasing in intensity and frequency both spatially and temporally. In the coming decades, the extent of drought risk and vulnerability is expected to increase irrespective of changes in drought exposure mainly due to development pressure, population increase, and environmental degradation (ISDR, 2002; Adger, 2006). As a result of growing vulnerability of people to underlying socio-economic and environmental changes induced by recurrent droughts, coping mechanism and long-term adaptation strategies are certain to change with major changes in livelihood options.

Keeping in view the changing circumstances, appropriate policy needs to be formulated for adapting to increasing vulnerability and a precautionary approach at different levels is essential. Rural people's perceptions on drought and climate change vulnerability form important tool for devising a rational mitigation strategy to reduce their vulnerability. The experiences and perceptions of farmers help in understanding the grass root level changes in local climate and their effects on agriculture, water and environment among others, which are free from any media and political biases.

In this context, this paper analyses the perceptions of the farmers on various aspects of present as well as future vulnerability to drought and climate change in Bolangir District of western Odisha. The changes in various climatic factors like rainfall, temperature, drought frequency and intensity during last three decades have been assessed. The farmers' experiences on hardships faced, natural and human induced causes of the changes observed have been examined. The perceptions on changes/trend in various vulnerability factors such as water availability, soil quality, early warning system, deforestation, social safety nets, institutional support system, degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species etc. have been scrutinized.

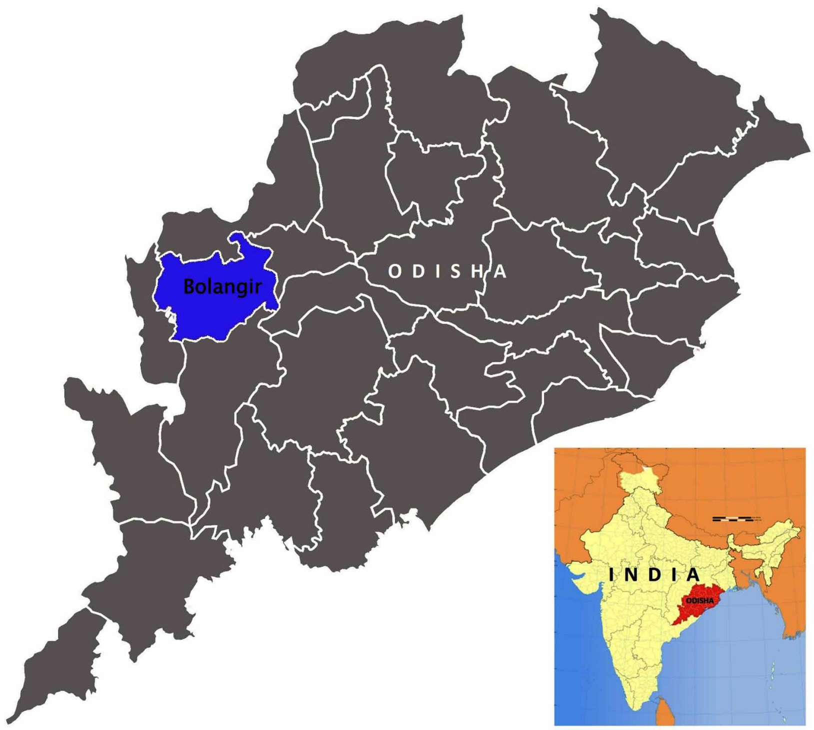
2. DATA AND METHODOLOGY

2.1. The Study Region

Bolangir district of western Orissa which is named after the headquarter town of Bolangir lies between 20° 11' 40" - 21° 05' 08" North Latitude and 82° 41' 15" - 83° 40' 22" East Longitude (Figure 1). The district is one of the constituent districts of the KBK (Kalahandi-Bolangir-Koraput) region of Orissa[2]. The district is situated in the valley of rivers like *Ang* and *Tel* with important tributaries like *Lanth, Sonegarh & Suktel*. The district is flanked by the Gandhamardan hill range in the north-west, Bargarh district to the north, Sonepur to the east, Kalahandi to the south and Nuapada to the west (GOO, 2006). The geographical area of the district is 6,569 sq. km, and has a population of about 1.34 million (GOI, 2001). The district has three sub-divisions (Bolangir, Patnagarh and Titlagarh), 6 Tahasils, 14 community development blocks (CD blocks), 285 gram panchayats, 1792 villages and 6 rural assembly constituencies. The proportion of rural population is much higher (88.45%) in the district and so also in the entire KBK region. The proportion of scheduled castes (SCs) and scheduled tribe (STs) in total population was around

16.9 percent and 20.6 percent respectively. The population growth rate was about 16 percent during 1981-1991 which was declined to 8.5 percent during the period from 1991 to 2001, the lowest population growth in the state. Out of a total geographical area of 657 thousand hectares, about 47.8 per cent is net sown area and 23.4 per cent is covered under forests. Analyzing the soil characteristics of Bolangir (Pattnaik, 1998), it reveals

Figure 1. The study region (India → Odisha → Bolangir)



that major portion of the cultivated area (around 50%) is characterized by loamy soil, 30 per cent is clayey, and 20 per cent is of sandy and other textured. The available water holding capacity (AWC) of about 80 per cent soils in Bolangir is medium (170 to 200mm), while that of 15-20 per cent soils in Bolangir have low to medium AWC of soil. Poverty, illiteracy and unemployment are widespread in the district. About 2.01 lakh families comprising 61.1 per cent of total are below the poverty line in the district. Agriculture is the predominant source of livelihood for the people in the district. Out of total population of 1.34 million, the working population constituted about 41 per cent. Of these, 85 per cent were counted as main workers. Four out of five main workers are either owner cultivators or agricultural labourers. Agricultural labourer households constitute about 52.7 per cent of total main workers (GOI, 2001).

Drought is a recurring and single most insidious phenomenon in Bolangir district of western Odisha. The recurrent drought phenomenon in the region is mostly responsible for its 'chronic backwardness' and widespread seasonal outmigration (Pattnaik, 1998). The increasing frequency of occurrence of the hazard is one of the major factors behind the rising level of drought vulnerability in the region, which is mainly due to larger variability in rainfall from season to season, rather than deficiency in amount of annual rainfall (Sainath, 1996; Swain, 2006). Another major factor for increasing drought frequency and vulnerability in Bolangir is the low irrigation coverage and neglect of the traditional water-harvesting structures (Nayak, 2004; Roy et al., 2004). The irrigation coverage in the district hovers around 23 per cent and the major sources of irrigation are dug wells and other water-harvesting structures (Swain et al., 2009).

2.2. Data and Sampling Design

The study is based on both secondary and primary data. The secondary data on irrigation coverage, crop insurance and funds flow for drought management etc. were analyzed. In this study we used a purposive multi-stage stratified sampling method to select 139 sample households. At the first stage, Bolangir district located in western part of Orissa was deliberately chosen for the study since it was found as the most vulnerable to drought among all the districts of Orissa (Roy et al., 2002; Roy et al. 2004) and the entire district was declared as the drought prone by the Government of India. In the second stage, three blocks Saintala (most vulnerable), Patnagarh (moderately vulnerable), and Titlagarh (least vulnerable) were selected on the basis of degree of drought vulnerability[3]. In the third stage, three villages, one from each of the identified blocks, were selected purposively considering their suitability for the study purpose and the degree of their representation for their respective blocks in terms of socio-economic and biophysical factors. Finally, households (HHs) were sampled and chosen from each of the selected villages using a stratified random sampling approach covering twelve major livelihood groups[4]. The reference year for the household survey was 2002 during which severe drought had affected the entire study region.

2.3. Analytical Tools

The present and future vulnerability to climate change has been assessed by ranking the vulnerability factors (economic/environmental/social/institutional) with respect to their effects during past, present and future climatic risks in the matrix form using a scale of 1 to 5. The ranking helped to identify the vulnerability factors that are expected to pose greater threat in future. The average ranking also helped to identify the relative strength of effects of various vulnerability factors that are posing greater threat.

3. PERCEPTIONS OF HOUSEHOLDS ON DROUGHT VULNERABILITY

The perception of sample households varied enormously. However, these were valuable for understanding different aspects of drought vulnerability such as the intensity and frequency of drought occurrence, nature of rainfall distribution, rainfall sufficiency, nature and degree of hardships faced by rural households. Their perceptions were very helpful in unfolding different localized natural and human induced causes of drought vulnerability and risks. Their perceptions on trends in drought vulnerability factors were really useful in identifying and prioritizing the important risk factors for the vulnerable households in the study region.

3.1. Perceptions on Drought Frequency, Drought Intensity, and Rainfall Pattern

As per the perceptions of rural households stated in Table 1, about 5.1 numbers of droughts have occurred in the study region during the last decade (1994-95 to 2004-05). The average numbers of occurrence of drought per decade in the region during last 20 years and last 30 years prior to 1994-95 were 6.9 and 9.3 respectively which reveals that the frequency of occurrence of drought has successively increased in the region. As far as the severity of drought is concerned, people faced very severe drought situation during both 2002 and 1996 with rank value of 4.9 each out of 5. However, the intensity of drought of 2000 and 1998 was little less with score of 4.8 and 4.3 respectively. The occurrence of drought in 2002 was due to early season rainfall failure which was intensified due to deficient rainfall during the last phase of agri-

Table 1. Perceptions of different livelihood groups on drought frequency and intensity

Sl. No.	Livelihood Groups	No. of Droughts in Last-			Degree of Intensity* of Major Droughts in last Decade			
		10 Years (1994-95 to 2004-05)	20 Years (1984-85 to 2004-05)	30 Years (1974-75 to 2004-05)	2002	2000	1998	1996
1	2	3	4	5	6	7	8	9
1	Cultivator	4.8	6.7	9.0	5.0	4.6	4.2	5.0
	(a) LF	4.7	6.9	8.5	5.0	4.5	4.0	5.0
	(b) MDF	4.4	6.1	9.0	5.0	4.5	4.5	4.9
	(c) SF	5.0	7.2	9.0	4.9	4.8	4.0	4.9
	(d) MF	5.0	6.5	9.5	5.0	4.5	4.2	5.0
2	Agricultural Labourer	5.3	6.8	9.5	4.9	4.6	4.2	5.0
	(a) Landless	5.5	7.0	9.5	4.9	4.8	4.3	5.0
	(b) With Marginal land	5.0	6.5	9.5	5.0	4.5	4.2	5.0
3	Non-Agrl Labourer	5.0	6.5	9.5	5.0	4.5	4.2	5.0
4	Rural Artisan	5.5	7.0	9.5	4.9	4.8	4.3	
5	Businessman	5.3	6.8	9.5	4.9	4.6	4.2	5.0
6	Forest Resources Dependant	5.3	6.8	9.5	4.9	4.6	4.2	5.0
7	Service Holder	4.5	6.5	8.8	5.0	4.5	4.3	5.0
8	Livestock Rearer	5.1	6.6	9.5	5.0	4.6	4.2	5.0
9	Others	5.5	7.0	9.5	4.9	4.8	4.3	4.9
All LGs		5.1	6.9	9.3	4.9	4.7	4.2	5.0

Note: *1 implies nil or negligible intensity and 5 refers to maximum level of intensity (in a 1 to 5 point scale)

Source: Field survey.

cultural season. However, the droughts of 1998 and 2000 were mainly late season drought and the drought of 1996 was characterized by a rainfall failure during the mid-season that was extended till the end of agricultural season.

The common perception of rural households on the bahaviour of rainfall during these drought years was that both amount and distribution of rainfall were highly unusual. The score for the amount of rainfall or sufficiency of rainfall during the drought year 2002 was just one indicating the fact that rainfall amount was very less (Table 2). However, the rainfall amount was little more during 2001 and 1998 compared to 2000 and 2002. However, the distribution of rainfall was revealed to be highly erratic. The perception score on distribution of rainfall varied from 1.0 (highly erratic) to 1.8 (around moderately erratic).

3.2 Perceptions of Livelihood Groups on Hardships Faced during Drought

Table 3 shows the perceptions of households on the hardships faced during the drought situations.

Table 2. Perceptions of livelihood groups on rainfall pattern

Sl. No.	Livelihood Group	Rainfall Pattern									
		Amount/ Sufficiency #					Distribution # #				
		2002	2001	2000	1998	1996	2002	2001	2000	1998	1996
1	2	3	4	5	6	7	8	9	10	11	12
1	Cultivator	1.0	2.5	1.0	2.0	1.0	1.0	1.7	1.1	1.6	1.0
	(a) LF	1.0	2.5	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0
	(b) MDF	1.0	2.5	1.0	2.0	1.0	1.0	2.1	1.0	2.0	1.0
	(c) SF	1.0	2.3	1.0	2.1	1.0	1.0	2.2	1.1	2.0	1.0
	(d) MF	1.0	2.5	1.1	2.0	1.0	1.0	1.6	1.2	1.3	1.0
2	Agricultural Labourer	1.0	2.5	1.1	1.7	1.0	1.0	2.3	1.1	1.6	1.0
	(a) Landless	1.0	2.4	1.0	2.0	1.0	1.0	1.9	1.1	1.6	1.0
	(b) With Marginal land	1.0	2.6	1.1	1.5	1.0	1.0	2.8	1.1	1.6	1.0
3	Non-Agrl Labourer	1.0	2.5	1.1	1.6	1.0	1.0	2.5	1.1	1.6	1.0
4	Rural Artisan	1.0	2.1	1.0	1.0	1.0	1.0				
5	Businessman	1.0	2.4	1.0	2.0	1.0	1.0	1.9	1.1	1.8	1.0
6	Forest Resources Dependant	1.0	2.2	1.2	2.5	1.0	1.0	2.5	1.1	1.9	1.0
7	Service Holder	1.0	2.5	1.8	2.2	1.0	1.0	2.1	1.2	2.0	1.0
8	Livestock Rearer	1.0	2.3	1.1	1.8	1.0	1.0	1.9	1.5	1.2	1.0
9	Others	1.0	2.2	1.1	1.8	1.0	1.0	2.2	1.1	1.7	1.0
All Households		1.0	2.4	1.0	2.0	1.0	1.0	1.8	1.1	1.6	1.0

Notes: # Codes to follow: Very less-1, little less-2 Sufficient-3 (compared with normal rainfall)

Codes to follow: highly erratic-1, moderately eratic-2 less erratic-3, more even-4, no change-5 (compared with normal rainfall)

Source: Field level survey.

It may be noted that the extent of hardships faced during drought of 2002 and 1996 were much larger compared to the same during other drought years. Out of the maximum score of 5, the average score for hardships faced by the households during the drought of 2002 was 4.3 while it was 4.9 during 1996. Though the intensity of the droughts of 2002 and 1996 was similar as found earlier, the extent of hardships caused by these two droughts was much different. Particularly, it was less during the drought of 2002 compared to the drought of 1996 due to increased preparedness. On the other hand, among different kinds of natural disasters faced by the households, it is distinctly drought and temperature increase that happened to affect the sample households significantly. The average impact scores for drought and temperature increase were 4.6 and 3.3 respectively, while the same for cyclone and flood were only 1.9 and 2.9 respectively.

Among different livelihood groups, small farmers were found to endure more hardships followed by landless agricultural labourers and rural artisans. The average hardship score varied from 3.8 to 4.5 among farmer categories. For landless agricultural labourers, the score was as high as 4.4 out of 5.

Table 3. Perceptions of livelihood groups on hardships faced during disaster period

Sl. No.	Livelihood Groups	Degree of Hardships Faced during Major Droughts in Last Decade*					Degree of Effects of Different Disasters*			
		2002	2001	2000	1998	1996	Drought	Cyclone	Flood	Temperature Extreme
1	2	3	4	5	6	7	8	9	10	11
1	Cultivator	4.2	3.2	3.7	2.8	4.9	4.5	1.5	2.7	3.0
	(a) LF	4.3	4.0	3.5	2.8	5.0	4.3	1.8	2.1	2.6
	(b) MDF	3.8	3.0	3.6	2.7	4.8	4.4	1.5	2.8	3.1
	(c) SF	4.5	3.1	3.8	2.8	4.8	4.6	1.4	3.0	3.3
	(d) MF	4.2	2.9	3.9	2.8	5.0	4.9	1.3	3.8	3.9
2	Agricultural Labourer	4.3	2.9	3.8	2.8	4.9	4.8	3.2	3.1	3.7
	(a) Landless	4.4	3.0	3.8	2.8	4.9	4.6	1.4	2.5	3.6
	(b) With Marginal land	4.2	2.9	3.9	2.8	5.0	4.9	4.8	3.9	3.4
3	Non-Agrl Labourer	4.3	2.9	3.8	2.8	5.0	3.2	4.1	3.0	3.2
4	Rural Artisan	4.3	2.9	3.8	2.9	4.9	3.1	3.2	1.5	3.1
5	Businessman	4.2	3.0	3.7	2.8	4.9	3.1	1.4	2.9	3.4
6	Forest Resources Dependant	4.3	2.9	3.8	2.6	4.9	4.7	1.4	3.3	4.1
7	Service Holder	2.4	1.2	2.3	1.4	2.7	2.1	1.6	1.9	1.9
8	Livestock Rearer	4.3	2.9	3.8	2.8	4.9	3.8	3.6	3.9	3.6
9	Others	4.0	2.9	3.6	2.7	4.9	2.7	2.0	3.4	3.1
All Households		4.3	3.1	3.7	2.8	4.9	4.6	1.9	2.9	3.3

Note: *1 implies nil or negligible level, while 5 refers to maximum level of hardships faced (in a 1 to 5 point scale)

Source: Field level survey.

3.3. Perceptions on Natural and Human Induced Causes of Drought

As regards different natural causes of recurrent drought in the study area, majority of 69.5 per cent of households perceived that it is the wide variability of rainfall, not inadequacy, which was the major reason for exacerbating drought situation in their region (Table 4). Only 24.7 per cent of households felt that both inadequacy of rainfall and erraticity of rainfall were responsible for rising level of susceptibility to drought. About 46. 3% of respondents supported the view that the lack of irrigation facilities due to uneven and hilly topography of the region was responsible for increasing drought vulnerability in the region. Nearly 51.1 per cent of respondents opined that the land slope was much more than the reasonable level that drained out rain water causing water scarcity in the region. About 31.5 per cent of respondents revealed that the lack of soil moisture or low water holding capacity of soil was a significant factor causing water scarcity during different agricultural seasons that increases the vulnerability of farmers to drought.

Table 5 displays the perceptions of the rural households on different human induced causes of drought vulnerability in the region. Among

Table 4. Perceptions of different livelihood groups on Natural causesof recurrent drought situations

Sl. No.	Livelihood Group	% of Respondents Answering 'yes' *									% Not Responded
		NC1	NC2	NC3	NC4	NC5	NC6	NC7	NC8	NC9	
1	2	3	4	5	6	7	8	9	10	11	12
1	Cultivator	7.5	70.9	26.7	49.8	14.9	43.6	21.6	31.4	3.0	0.9
	(a) LF	5.9	76.5	24.3	58.8	11.8	47.1	23.5	29.4	0.0	0.0
	(b) MDF	8.0	68.0	22.0	48.0	12.0	40.0	16.0	28.0	4.0	0.0
	(c) SF	8.7	65.2	29.1	47.8	17.4	39.1	17.4	34.8	4.3	0.0
	(d) MF	7.4	74.1	26.7	44.4	18.5	48.1	29.6	33.3	3.7	3.7
2	Agricultural Labourer	8.2	71.2	27.7	46.6	15.1	49.3	26.0	32.9	4.1	2.7
	(a) Landless	8.5	68.1	21.9	48.9	10.6	48.9	25.5	31.9	4.3	2.1
	(b) With Marginal land	7.7	76.9	28.8	46.2	19.2	50.0	26.9	34.6	3.8	3.8
3	Non-Agrl Labourer	7.7	73.1	22.2	46.2	19.2	50.0	26.9	34.6	3.8	3.8
4	Rural Artisan	11.1	66.7	11.8	55.6	22.2	44.4	11.1	22.2	0.0	11.1
5	Businessman	3.2	71.0	13.3	61.3	16.1	48.4	12.9	35.5	3.2	3.2
6	Forest Resources Dependant	7.4	68.5	21.0	44.4	14.8	35.2	20.4	33.3	3.7	3.7
7	Service Holder	7.7	69.2	19.8	53.8	15.4	46.2	23.1	38.5	7.7	0.0
8	Livestock Rearer	7.7	69.2	25.4	46.2	15.4	46.2	23.1	30.8	0.0	0.0
9	Others	9.1	72.7	19.4	45.5	18.2	45.5	18.2	27.3	0.0	0.0
All households		8.0	69.5	24.7	51.1	12.8	46.3	23.6	31.5	3.6	1.5

Notes: *Major natural causes are as follows:

NC1. Only Inadequacy of rainfall, not erraticity

NC2. Wide variability of rainfall, not inadequacy

NC3. Both Inadequacy and erraticity of rainfall

NC4. Land type is too sloppy that drains out rain

NC5. Location of major lands is such that it neither can be irrigated nor can hold rainfall and soil moisture

NC6. Lack of irrigation facilities due to natural topography of the region

NC7. Lack of irrigation due to inadequate water resources

NC8. Lack of soil moisture or soil is incapable of holding moisture

NC9. Any Other

Source: Field level survey.

Table 5. Perceptions of different livelihood groups on human induced causes of recurrent drought situations

Sl. No.	Livelihood Group	% of Respondents with Positive Response*													% Not Responded
		HC 1	HC 2	HC 3	HC 4	HC 5	HC 6	HC 7	HC 8	HC 9	HC 10	HC 11	HC 12	HC 13	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Cultivator	72.1	78.3	17.4	19.9	62.1	21.3	17.5	56.7	48.6	27.7	61.4	55.5	13.5	0.0
	(a) LF	76.5	82.4	17.6	23.5	64.7	17.6	17.6	58.8	82.4	23.5	47.1	82.4	23.5	0.0
	(b) MDF	72.0	80.0	16.0	20.0	60.0	20.0	20.0	56.0	36.0	28.0	60.0	56.0	12.0	0.0
	(c) SF	69.6	69.6	17.4	17.4	60.9	21.7	17.4	56.5	39.1	26.1	60.9	39.1	0.0	0.0
	(d) MF	70.4	81.5	18.5	18.5	63.0	25.9	14.8	55.6	37.0	33.3	77.8	44.4	18.5	0.0
2	Agricultural Labourer	69.9	82.2	19.2	20.5	52.1	21.9	15.1	52.1	34.2	35.6	74.0	46.6	26.0	2.7
	(a) Landless	70.2	85.1	19.1	21.3	59.6	19.1	17.0	48.9	31.9	38.3	72.3	51.1	34.0	2.1
	(b) With Marginal land	69.2	80.8	19.2	19.2	61.5	26.9	11.5	53.8	34.6	34.6	76.9	42.3	19.2	0.0
3	Non-Agrl Labourer	69.2	80.8	19.2	19.2	57.7	23.1	15.4	53.8	34.6	34.6	76.9	76.9	23.1	3.8
4	Rural Artisan	66.7	88.9	11.1	11.1	55.6	22.2	11.1	55.6	44.4	55.6	22.2	33.3	0.0	0.0
5	Businessman	77.4	83.9	12.9	19.4	64.5	22.6	16.1	48.4	64.5	25.8	54.8	77.4	22.6	3.2
6	Forest Resources Dependant	77.8	88.9	11.1	16.7	63.0	25.9	16.7	51.9	68.5	48.1	68.5	31.5	1.9	3.7
7	Service Holder	84.6	92.3	15.4	7.7	61.5	15.4	15.4	61.5	84.6	23.1	38.5	84.6	30.8	0.0
8	Livestock Rearer	76.9	84.6	15.4	15.4	61.5	23.1	15.4	53.8	53.8	46.2	53.8	38.5	15.4	0.0
9	Others	72.7	81.8	18.2	18.2	54.5	18.2	18.2	54.5	54.5	45.5	54.5	36.4	9.1	0.0
All Households		71.2	81.7	18.3	20.6	60.9	20.2	17.2	52.8	40.3	33.0	66.9	53.3	23.8	1.1

Notes: *Major human-induced causes are as follows:

HC1. Lack of irrigation projects due to inefficient governmental effort though there is a viable option

HC2. Lack of irrigation from WHSs though possible

HC3. Poor irrigation water management at local level

HC4. Poor crop selection

HC5. No early warning was transmitted through responsible authorities at local level

HC6. Early warning was given but too late for which crop planning could not be changed

HC7. Did not believe on early warning though it was given at right time

HC8. Watershed is not developed

HC9. Though watershed was developed, it couldn't be sustained

HC10. Lack of awareness/Ignorant about what to do

HC11. Unable to invest on drought mitigation measures due to poor socio-economic status/exploitation by land lord, private money lender or local Zamindar

HC12. Deforestation and

HC13. Any other (lack of coordination among people, political negligence etc.)

Source: Field level survey.

human induced causes of drought, 81.7 per cent of respondents expressed their view that the major human induced cause of recurrent drought situation in the region is the lack of irrigation due to negligence of water harvesting structures (WHSs). Though it is possible to increase the irrigation coverage through WHSs in the region due to conducive biophysical and socio-economic factors, the institutional support is not sufficient as per the views of the farmers.

Among other human induced causes of drought vulnerability, the inability to invest on drought mitigation measures due to poor socio-economic condition or exploitation by landlord, private money lenders, low performance of watershed programmes, poor early warning mechanism, and low level of awareness/Ignorance among the people in the region were found to exacerbating the drought vulnerability in the study region. Nearly 67 per cent of respondents expressed their inability to invest on drought mitigation measures for which their susceptibility to drought is increasing. About 53.3 per cent of respondents believed that the large-scale deforestation contributed greatly to the rising level of drought vulnerability in the region. Though the extent of awareness on recently developed drought management practices is low, 54.5 per cent of respondents felt that the extent of awareness among farmers has increased in recent years. However, about 61 per cent of respondents asserted that no early warning was transmitted by responsible authorities at local level at the right time during the drought year. About 20.2 per cent respondents revealed that early warning was given but it was too late for which crop planning could not be changed. Unfortunately, 17.2 per cent farmers did not believe the occurrence of the drought even if they had received the information at the right time.

3.4. Perceptions on Changes in Drought Vulnerability Factors

As discussed earlier, many environmental and socio-economic changes have been observed over the years in Bolangir. The changes in the environmental factors in the region indicate that the process of desertification has already set in motion. The mean maximum temperature of the district has steadily increased and the mean minimum temperature has fallen during the same period. On the other hand, the region is also facing acute problem in socio-economic fronts. The situation in Bolangir has worsened with rapid deforestation. The levels of poverty, illiteracy and impoverishment in such a backward region have not decreased to the desirable extent in spite of significant achievements at macroeconomic level.

In this section, we have analyzed the kind of changes that have experienced by sample households. As Table 6 shows, 72.6 per cent of respondents recalled that in relation to past decades, the average annual rainfall has fallen and has become more and more erratic. Nearly 66.5 per cent respondents felt that the night temperature is declining and day temperature is increasing over the years.

About 85 per cent respondents revealed that the irrigation coverage in their locality has been stagnated over the years. The farmers also expressed that the irrigated area under WHSs has declined due to negligence at different levels as only 6.2 per cent of them supported the statement that it has increased in the region. On the other hand, 32.6 per cent of farmers felt that the soil is becoming less fertile and also losing the water holding capacity. Nearly 54.5 per cent of respondents felt that the awareness about the drought management practices has increased at present

Table 6. Perceptions of different livelihood groups on changes in drought vulnerability factors over the years

Sl. No.	Livelihood Group	Observed Changes in Drought Vulnerability Factors* (% Respondents Agreed)												% Not Responded
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F 10	F 11	F 12	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Cultivator	70.7	58.6	84.0	6.0	3.9	26.8	64.4	1.0	4.8	47.9	36.2	73.0	0.0
	(a) LF	70.6	47.1	88.2	11.8	0.0	23.5	70.6	0.0	0.0	47.1	29.4	76.5	0.0
	(b) MDF	76.0	56.0	88.0	0.0	4.0	20.0	68.0	4.0	0.0	40.0	28.0	80.0	0.0
	(c) SF	69.6	60.9	78.3	8.7	4.3	30.4	52.2	0.0	4.3	56.5	39.1	65.2	0.0
	(d) MF	66.7	70.4	81.5	3.7	7.4	33.3	66.7	0.0	14.8	48.1	48.1	70.4	0.0
2	Agricultural Labourer	71.2	72.6	86.3	6.8	5.5	35.6	56.2	1.4	17.8	46.6	60.3	71.2	2.7
	(a) Landless	74.5	74.5	85.1	6.4	2.1	38.3	44.7	4.3	21.3	44.7	51.1	70.2	2.1
	(b) With Marginal land	69.2	69.2	84.6	7.7	7.7	38.5	65.4	0.0	15.4	50.0	69.2	73.1	0.0
3	Non-Agrl Labourer	69.2	65.4	84.6	11.5	0.0	38.5	61.5	0.0	15.4	46.2	65.4	73.1	3.8
4	Rural Artisan	55.6	55.6	88.9	11.1	11.1	33.3	33.3	0.0	11.1	55.6	44.4	55.6	0.0
5	Businessman	71.0	61.3	83.9	6.5	3.2	22.6	77.4	3.2	12.9	48.4	58.1	71.0	3.2
6	Forest Resources Dependant	72.2	68.5	79.6	5.6	7.4	11.1	16.7	3.7	29.6	25.9	1.9	22.2	3.7
7	Service Holder	69.2	69.2	92.3	7.7	0.0	38.5	76.9	0.0	7.7	69.2	7.7	61.5	0.0
8	Livestock Rearer	69.2	53.8	84.6	7.7	7.7	23.1	30.8	0.0	7.7	30.8	30.8	30.8	0.0
9	Others	72.7	63.6	81.8	9.1	9.1	18.2	27.3	9.1	9.1	45.5	9.1	54.5	0.0
All Households		72.6	66.5	84.6	6.2	3.0	32.6	54.5	2.6	13.0	46.3	43.6	71.6	1.1

Notes: *Major propositions are as follows:

F1: Both rainfall is falling and becoming more erratic.

F2: Night temperature is declining and day temperature is increasing over the years.

F3: Irrigation coverage has been stagnated over the years.

F4: Irrigation from WHS s is increasing.

F5: Governmental effort for participatory irrigation management has increased.

F6: Soil is becoming less fertile and less able to hold moisture.

F7: Awareness about the drought management practices has increased.

F8: Early warning system has been strengthened.

F9: More sustainable treatment of watershed has been observed.

F10: Deforestation has increased significantly.

F11: Participatory management of common property resources has been emphasized and increased though not significantly.

F12: Not much meaningful long-term strategies have been adapted over the years to address these human induced causal factors.

compared to previous years. However, only 2.6 per cent respondents supported the statement that early warning system has been strengthened. More importantly, about 72 per cent respondents felt that no much meaningful long-term strategies have been adapted on sustainable basis over the years in the region.

Overall, the peoples' perceptions suggest that different biophysical factors of drought vulnerability like drought probability, rainfall amount and variability, increase in temperature are signaling that the extent of nature's fury is on rise in the region. On the other hand, the coping capacity of vulnerable households and the prevailing state of institutional support system are not adequate for reducing the level of drought vulnerability and risks.

4. TREND IN DROUGHT IMPACTS

Vulnerability to drought is dynamic in nature that changes over time depending on socio-economic and biophysical changes in a region. As we have mentioned earlier that the nature of changes in climatic factors in Bolangir shows that it is heading towards a gradual desertification. The mean maximum temperature is rising and the mean minimum temperature is falling. The long-term average rainfall is falling with rising level of erratic pattern of rainfall. We have also analyzed the present state of vulnerability to drought in the last chapter. To understand the future vulnerability, it is essential to analyze the trends in drought impacts. There was a need to understand the kind of drought impacts people were experiencing more in the past years; the kinds of impacts they observed more in the recent years; and the kinds of drought impacts that are anticipated to affect them more in coming years, are some of the important questions those were attempted to be answered in this section. We analyzed the peoples' perception in this regard as shown in Table 7.

With regard to the trends in drought impacts in terms of biophysical factors, it may be noted that all four major biophysical factors are signaling to the increasing trend, i.e., they are going to increase in the future years. In other words, they may result in more devastation in the future years. However, the strength of their trends varies a lot. The temperature variability, rainfall variability and drought frequency are exhibiting clear increasing trends; while the drought intensity has declined in recent years compared to the same during the past drought episodes, as perceived by the rural households.

So far as drought induced environmental risks are concerned, except the rate of deforestation, all other factors considered for analysis such as reduction and degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species are expected to pose greater risks in the coming years due to unplanned and irrational exploitation of these resources and also due to impacts of adverse climatic factors. In the past decade, the water bodies specifically micro level water resources were helping the farmers in tackling the drought induced water scarcity effectively. However, the risks of loss of these water bodies significantly increased in recent years. Due to lack of proper policy attentions despite a number of agitations by farmers and media hypes, peoples' perceptions indicate that their worry may increase on these accounts in future years. Also the peoples' perceptions on social and institutional fronts do not indicate any better prospects. Among the selected indicators, the water user conflicts, political/management conflicts, reduction in quality of life are exhibiting clear increasing trend. The respondents felt that the conflicts over the irrigation water allocation and distribution would continue to increase due to reduced size of utilizable water resources. The increasing occurrence of political and management conflicts, political nepotism and corruption are expected to further increase the vulnerability

Table 7. Prioritization and trends in drought impacts

(Average of Ranks)				
Sl. No.	**Drought Impacts***	**Past Drought Events (During Last Decade or Back)**	**Current Drought Event (Last One, i.e., 2002)**	**Future Drought Events**
1	**2**	**3**	**4**	**5**
Drought Characteristics				
1	Drought Frequency	3.3	4.2	4.8
2	Drought Intensity	3.7	3.6	3.9
3	Rainfall Variability	3.6	4.3	4.8
4	Temperature Variability	2.7	3.1	3.8
Economic Impacts				
(A) Loss from Crop Farming				
5	Annual or perennial crop losses	4.0	3.6	4.4
6	Damage to crop quality	4.2	3.0	3.6
7	Reduced crop productivity	4.4	3.2	3.6
8	Insect infestation	2.8	4.0	5.0
9	Plant diseases	3.0	4.0	5.0
10	Income loss of farmers	4.0	3.5	4.0
11	Bankruptcy of farmers	3.5	3.1	4.5
12	Unemployment from production decline	3.0	4.0	5.0
13	Increase in food prices	2.5	3.5	4.3
14	Disruption in water supplies	3.0	4.0	5.0
15	Decreased land prices	1.0	2.0	2.0
16	Increasing trends of fallow lands	5.0	3.3	2.3
17	Sale of farm assets and durables	4.0	1.8	3.5
(B) Loss from Dairy and Livestock Production				
18	High livestock mortality rate	4.0	2.0	1.0
19	Breeding delays or decreased pregnancies	2.0	4.0	5.0
20	Low prices for livestock products	2.0	3.0	4.0
21	Grazing land and fodder availability	1.7	3.0	4.0
(C) Loss from Fishery and Forest Livelihood Losses				
21	Loss from fishery production	3.0	3.5	4.5
22	Damage to fish habitat	3.0	3.5	4.5
23	Loss of young fish due to decreased flows	3.0	3.5	4.5
24	Loss from timber production	3.0	3.0	4.5
25	Less access to non-timber forest produces	1.7	3.7	4.7

continued on following page

Table 7. Continued

(Average of Ranks)				
Sl. No.	**Drought Impacts***	**Past Drought Events (During Last Decade or Back)**	**Current Drought Event (Last One, i.e., 2002)**	**Future Drought Events**
1	**2**	**3**	**4**	**5**
Environmental Impacts				
26	Reduction and degradation of wild life habitat	1.7	4.0	5.0
27	Shortage of feed and drinking water	2.0	3.7	4.7
31	Loss of wetland and water bodies	1.2	3.9	4.4
32	Damage to plant species	2.3	4.2	4.6
33	Deforestation	1.3	3.9	2.1
Social/Institutional Ixmpacts				
34	Mental/physical stress	4.3	3.0	4.7
35	Reductions in nutrition	5.0	2.0	4.0
36	Loss of human life (Due to suicide, starvation)	4.7	2.3	2.7
37	Water user conflicts	2.3	3.0	3.7
38	Political/management conflicts	1.0	2.0	3.0
39	Disruption of cultural belief system	4.0	3.0	2.0
40	Public dissatisfaction with governments	2.7	3.7	3.3
41	Inequity in distribution of drought relief	2.1	3.3	4.4
42	Reduced quality of life	1.0	4.0	5.0
43	Migration from rural to urban	2.0	3.3	5.0
44	Reduced standard of living	2.0	3.0	2.0
Note:* Drought impacts are ranked from 1 to 5. The rank 1 implies negligible or nil influence; while the rank 5 implies maximum influence.				
Source: Farm level survey.				

of rural poor. The quality of life is perceived to be deteriorated in the coming days due to rising degradation in environmental, social and economic spheres. On all these accounts, the mental and physical stress levels are expected to increase for vulnerable rural poor.

5. CONCLUSION

Rural people's perceptions on drought and climate change vulnerability are essential for devising a rational mitigation strategy to reduce their vulnerability. The paper analyses the perceptions of the farmers on various aspects of present as well as future vulnerability to drought and climate change in western Odisha. The changes in various climatic factors like rainfall, temperature, drought frequency and intensity during last three decades have been assessed. The farmers' experiences on hardships faced, natural and human induced causes of the changes observed have been examined. The perceptions on changes/trend in various vulnerability factors such as water availability, soil quality, early warning system, deforestation, social safety nets, institutional support system, degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species etc. have been scrutinized. Besides, the future vulnerability to climate change has been assessed by ranking the vulnerability factors (economic/environmental/social/institutional) with respect to their effects during past, present and future climatic risks in the matrix form using a scale of 1 to 5. The ranking helped to identify the vulnerability factors that are expected to pose greater threat in future. The average ranking also helped to identify the relative strength of effects of various vulnerability factors that are posing greater threat. The study is based on the survey of 139 households.

The perceptions of sample households varied enormously. However, these were valuable for understanding different aspects of drought vulnerability such as the intensity and frequency of drought occurrence, nature of rainfall distribution, rainfall sufficiency, nature and degree of hardships faced by rural households. Their perceptions were very helpful in unfolding different localized natural and human induced causes of drought vulnerability and risks. Their perceptions on trends in drought vulnerability factors were really useful in identifying and prioritizing the important risk factors for the vulnerable households in the study region. The nature of changes in climatic factors in western Odisha shows that it is heading towards a gradual desertification. The mean maximum temperature of the district has steadily increased and the mean minimum temperature has fallen during the same period. Nearly 66.5 per cent respondents felt that the night temperature is declining and day temperature is increasing over the years. On the other hand, the region is also facing acute problem in socio-economic fronts. The situation in Bolangir has worsened with rapid deforestation. The levels of poverty, illiteracy and impoverishment in such a backward region have not decreased to the desirable extent in spite of significant achievements at macroeconomic level.

The factors that are posing greater threat in future are increasing temperature and rainfall variability, frequent pest attack and plant diseases, gradual decline in grazing land and fodder availability, reduction and degradation of wild life habitat and loss of wetland and water bodies. The temperature variability, rainfall variability and drought frequency are exhibiting clear increasing trends; while the drought intensity has declined in recent years compared to the same during the past drought episodes, as perceived by the rural households. Among different economic impacts of drought related to crop farming, the impacts showing clear increasing trend are drought induced insect infestation and plant diseases, disruption in water supply, unemployment from production decline and increase in food prices. Due to increasing frequency of drought and moisture stress, the resistivity of plants is gradually falling, that in turn, results in increasing risks of frequent pest attack. Among other economic impacts, the risks on accounts of grazing land and fodder availability, loss from fishery production, damage to fish habitat, loss of young fish due to decreased flows, loss from timber production, and less access to non-timber forest produces by the poor are expected to increase in future years. So far as drought induced environmental risks are concerned, except the rate of deforestation, all other factors considered for analysis such as reduction and degradation of wild life habitat, loss of wetland and water bodies, and damage to plant species are expected to pose greater risks in the coming years due to unplanned and irrational exploitation of these resources and also due to impacts of adverse climatic factors. In the past decade, the water bodies specifically micro level water resources were helping the farmers in tackling the drought induced water scarcity effectively. However, the risks of loss of these water bodies significantly increased in recent years.

Also the peoples' perceptions on social and institutional fronts do not indicate any better prospects. Among the selected indicators, the water user conflicts, political/management conflicts, reduction in quality of life are exhibiting clear increasing trend. The respondents felt that the conflicts over the irrigation water allocation and distribution would continue to increase due to reduced size of utilizable water resources. The increasing occurrence of political and management conflicts, political nepotism and corruption are expected to further increase the vulnerability of rural poor. The quality of life is perceived to be deteriorated in the coming days due to rising degradation in environmental, social and economic spheres. On all these accounts, the mental and physical stress levels are expected to increase for vulnerable rural poor.

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ENDNOTES

[1] This paper is a part PhD work (2009) of the author that was undertaken at NKC Centre for Development Studies (ICSSR), Bhubaneswar by availing ICSSR doctoral fellowship. Author wishes to thank Dr. Mamata Swain, Professor of Economics and Dean, School of Social Sciences, Ravenshaw University, Cuttack and Dr. S. Meher of NKC Centre for Development Studies, Bhubaneswar (ICSSR) for their useful comments on the draft paper.

[2] The KBK region was earlier constituted by three districts namely, Kalahandi, Bolangir and Koraput which were divided into eight districts later on in 1992-93. The eight districts of KBK region are Kalahandi, Nuapara, Bolangir, Sonepur, Koraput, Rayagada, Nowrangpur and Malkanagiri. These districts in western Orissa are well known for prevalence of chronic poverty, widespread illiteracy, malnutrition and periodic out migration (Action Aid, 2001)

[3] The degree of drought vulnerability in the blocks was estimated according to the value of Composite Drought Vulnerability Index (CDVI) constructed on the basis of ranks or weights attached to nineteen key drought vulnerability factors out of which six were biophysical factors (i.e., drought probability, intensity, long-term rainfall variability, water holding capacity of soil, land slope, and ground water table) and thirteen were socio-economic factors (poverty, education, irrigation, major crop production, land use pattern and some important institutional factors).

[4] The twelve major livelihood groups were: large farmer (average size of operational area of more than 4 hectares), medium farmer (2 -4 hectares), small farmer (1-2 hectares), marginal farmer (up to 1 hectare), agricultural labourer, non-agricultural labourer, forest resource dependant, rural artisan, businessman, service holder, livestock rearer, and others covering fishing community, stone merchants, and tailors.

Section 3
Natural Disaster

Chapter 8
What Causes Economic Losses from Natural Disasters in India?

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ABSTRACT

The reported economic losses due to natural disasters show an increasing trend over time for India. This is due to the influence of three factors: bio-physical drivers, exposure and vulnerability. Normalising the influence of exposure and vulnerability of socio-economic factors, this chapter potentially detects the influence of climate, caused by natural climate variability as well as anthropogenic climate change, in determining the damages from natural disasters. It analyses the trends in both the reported and normalised economic losses from natural disasters in India during 1964 and 2012. Similar analysis is also carried out for a subset of major disaster events like cyclonic storms and floods. No significant trend is found either for the normalised damage costs from natural disasters or for individual extreme events like floods and cyclonic storms. The findings suggest that the increases in damage costs is due to higher exposure and vulnerability of the socio-economic conditions of those affected, and recommends for additional investments on infrastructure to strengthen the adaptive capacity of the vulnerable sections with respect to the socio-economic factors.

1. INTRODUCTION

The global economic losses due to natural disasters have increased over time, and are likely to increase in the foreseeable future, especially in the developing countries (Botzen and van den Bergh, 2009; Intergovernmental Panel on Climate Change, hereafter, IPCC, 2012). The economic losses due to climate extremes were 1% of GDP (Gross Domestic Product) for developing nations during 2001-06, whereas it was 0.3% for low income nations and less than 0.1% for high

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income nations (IPCC, 2012). The recent 'atlas of mortality and economic losses from weather, climate and extreme events' by World Meteorological Organisation (WMO) reports that around 2,682 extreme events have occurred in Asia during 1970-2012, resulting in 0.92 million deaths and US$ 798.8 billion (adjusted at 2012 prices) of economic damages (WMO, 2014). Most of these disasters were attributed to incidence of floods and cyclonic storms, i.e., 45% and 35%, respectively (WMO, 2014). Based on EM-DAT international disaster database, it is found that the total damage costs due to natural disasters in India were US$ 2.92 billion during the 1970s. The extent of damage costs increased in the subsequent decades from US$ 5.92 billion during the 1980s to US$ 18.41 billion and US$ 23.74 billion during 1990s and 2000s, respectively. Further, Padmanabhan (2012) reports that the total economic damages due to extreme events were US$ 48.06 billion during the period 1980-2010 – this corresponds to an average of US$ 1.55 billion per annum during the same period with the direct losses touching about 2% of India's GDP.

It is imperative to note that the damages from natural disasters depend on: (i) climatic and geo-physical factors which derive the nature and intensity of a disaster event, and (ii) exposure and vulnerability of socio-economic factors that largely determine an event's ex-post impact (Schmidt *et al*., 2009; Neumayer and Barthel, 2011; IPCC, 2012; Bahinipati and Venkatachalam, 2014; Bahinipati and Patnaik, 2015). From a policy perspective, the onus is to reduce the potential impacts of natural disasters which calls for a better understanding of the drivers involved in the impact process. In order to estimate the influence of each of these factors, a 'normalisation technique' is being used in the literature, which isolates the role of climate and geo-physical factors from that of socio-economic factors to determine economic costs due to natural disasters (Bahinipati and Venkatachalam, 2014). Most of the normalisation studies dealing with natural disasters so far mainly focused on a global scale or on developed countries, especially the USA and the Europe (Pielke and Landsea, 1998; Pielke and Downton, 2000; Pielke *et al.*, 2003, 2008; Barredo, 2009, 2010; Schmidt *et al.*, 2010; Neumayer and Barthel, 2011; e.g. *see* Bouwer, 2011 and Table 1), because of the availability of long-term quality data. While data constrains remain, it is essential to conduct normalisation exercise in developing country contexts, where the anticipated impacts of natural disasters are likely to increase in the foreseeable future (Stern, 2007; IPCC, 2012). To the best of our knowledge, no study seems to have attempted the normalisation exercise in the Indian context although a few studies do exist at the regional level. For instance, while Raghavan and Rajesh (2003) focus on cyclonic storms in Andhra Pradesh, Bahinipati and Venkatachalam (2014) analyse three extreme events, namely cyclones, floods and droughts, together in the context of Odisha.

Against this backdrop, this chapter attempts to fill in this gap and carry out a normalisation analysis for a better understanding of the magnitude of economic losses due to natural disasters that occurred in India between 1964 and 2012[1]. The results are also validated by performing a similar type of analysis for individual disasters like floods and cyclonic storms, which are considered as the major extreme events in India. The objective of this chapter is to identify determinants of unprecedented increase in damage costs due to climate extremes in India. This chapter is structured as follows: the second section outlines theoretical underpinnings of normalisation technique, and the third section describes data and methods. Section four discusses empirical results, and the final section concludes with some policy suggestions.

Table 1. Survey of normalisation studies

Study	Extreme Events	Location	Period	Normalisation	Result
Pielke and Landsea (1998)	Hurricane	USA	1900-1995	Inflation, wealth and population	No trend since 1900
Pielke and Downton (2000)	Flood	USA	1932-1997	No adjustment Population Wealth	Increasing trend Increasing trend No trend
Changnon *et al.* (2000)	Weather extreme events	USA	1950-1997	Wealth, and value of land and property	Flat trend
Collin and Lowe (2001)	Hurricane	USA	1900-1999	Inflation, wealth and housing unit	No trend since 1900
Raghavan and Rajesh (2003)	Tropical storm	Andhra Pradesh, India	1977-1998	Income and population	No trend
Pielke *et al.* (2003)	Tropical storm	Latin America	1944-1999	Wealth and population	No trend
Pielke *et al.* (2008)	Tropical Storm	USA	1900-2005	Wealth and population	No trend since 1900
Crompton and McAneney (2008)	Weather (flood, thunderstorms, hail and bushfires)	Australia	1967-2006	Dwellings and dwelling values	No trend
Barredo (2009)	Flood	Europe	1970-2006	Wealth and population	No trend
Barredo (2010)	Windstorm	Europe	1970-2008	Wealth and population	No trend
Nordhaus (2010)	Hurricane	USA	1900-2008	GDP	Increasing trend since 1900 and ninth power law of damage
Schmidt *et al.* (2010)	Tropical storm	USA	1950-2005	Capital stock index	Socio-economic is three times greater than climate change
Neumayer and Barthel (2011)	Natural disaster	World	1980-2009	Same as Pielke and Landsea (1998) and GDP	No trend
Bouwer and Botzen (2011)	Hurricane	USA	1900-2005	Pielke and Landsea (1998), Collin and Lowe (2001) and Nordhaus (2010)	No trend, but elasticity is probably in the range of a 6.5 up to 8 power
Barthel and Neumayer (2012)	Geo-physical and non-geo-physical disasters	World USA Germany	1990-2008 1980-2008 1973-2008	Inflation, wealth and housing unit (depends on availability of data for different region)	No trend Increasing trend for geo-physical and specific disasters in USA and Germany
Simmons *et al.* (2013)	Tornado	USA	1950-2011	GDP based normalisation, county population and income based normalisation and national housing unit based normalisation	Long-term decline in trend/ no trend
Bahinipati and Venkatachalam (2014)	Natural disasters (cyclone, flood and drought)	Odisha, India	1972-2009	Inflation, Income and population Inflation, Income and Households	Increasing trend, but flatter than the trend line of reported economic losses

Source: Authors' review (updated from Bahinipati, 2013)

2. THEORETICAL UNDERPINNINGS OF NORMALISATION

A perfunctory analysis of the data on the reported losses from natural disasters in India reveals an increasing (or decreasing) trend over time, based on which, it is concluded that the intensity of such events is rising (or falling) due to increase (or decrease) in frequency and duration of such events. However, this under-estimates the influence of the location specific socio-economic factors in deriving the outcome of such events. The intensity and scale of impacts from extreme events, for instance, may increase in the current period as more elements are at risk in vulnerable regions (for example the number of people living in these regions may have increased or the extent of physical infrastructure or property may have grown over time). This is illustrated in Figures 1 and 2: while former explains the cases where intensities of extreme events are equal, the latter outlines the context where intensities are not equal.

In figures 1 and 2, the axes OX and OY represent years and impact cost (in US$ billion), respectively. The positive linear trend line 'A_0A_0' shows the actual impact cost, which is increasing over time. Suppose the physical intensity of two extreme events is similar in the given years 'Y_1' and 'Y_2'. This entails that the impact cost in both the years should be equal. However, the actual impact cost in the year 'Y_2' ('E_3Y_2') is higher than the 'Y_1' ('E_1Y_1'). Although the disaster events in the two years Y_1 and Y_2 characterize equal physical intensity, the actual impacts are diverse. The impact gap ('E_2E_3') is therefore due to the location specific economic characteristics and population growth, i.e. socio-economic factors.

As mentioned above, Figure 2 outlines the impact trend line with unequal physical intensity. In Figure 2, N_0N_0 shows the normalized impact cost, which is normalised under Y_1's societal condition; the difference between original and the normalised impact cost (i.e., E_3E_4) arises from the socio-economic factors. At point Y_2, the difference between the normalised impact cost line (i.e., N_0N_0) and equivalent the normalised year's cost E_2Y_2 (i.e., E_2E_4) is due to natural climate variability as well as anthropogenic climate change. Instead

Figure 1. Impact trend line with equal physical intensity
Source: Authors' derivation.

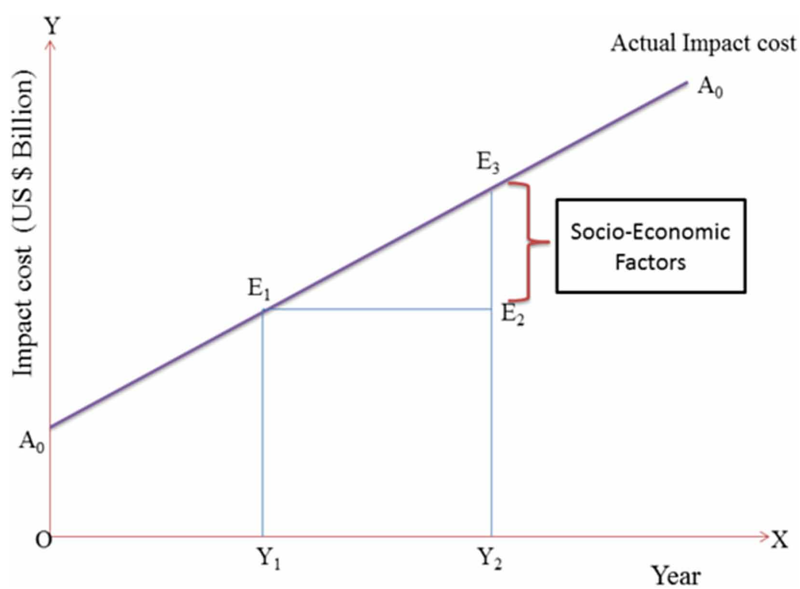
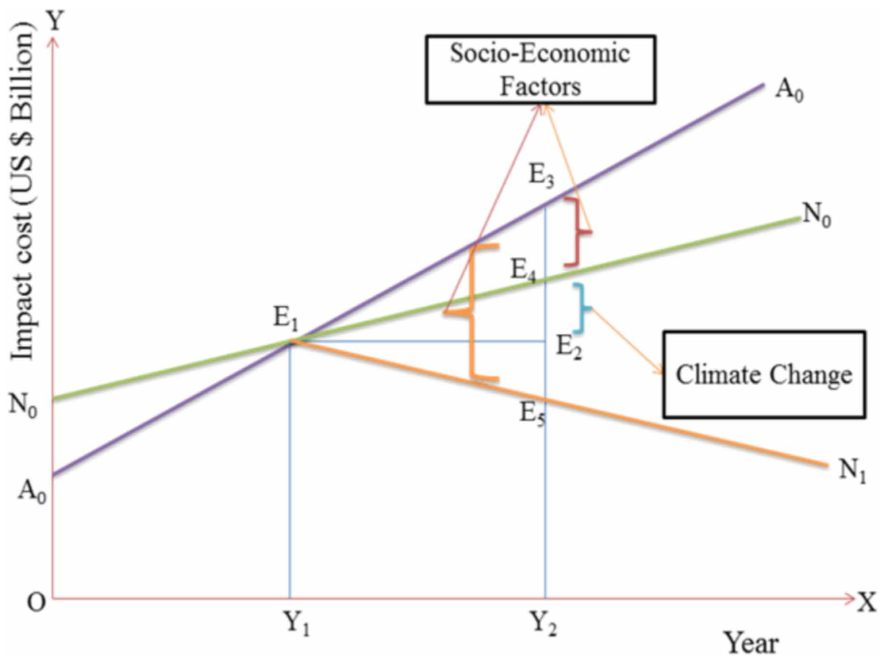


Figure 2. Impact trend line with unequal physical intensity
Source: Authors' derivation.



of N_0N_0, suppose we get a normalised impact cost line $N_0E_1N_1$ which shows a declining trend after the normalisation. The difference between original and the normalised impact cost line (i.e., E_3E_5) is attributed to the socio-economic factors.

As outlined in the introduction section of this chapter, normalisation technique segregates the role of climate change on damages due to climate extremes from that of the socio-economic factors. Table 1 summarises a few normalisation studies (see Bouwer, 2011 for a comprehensive survey). From this table, it is observed that the findings of the normalisation studies are mixed. While the studies by Pielke and Downton (2000) and Nordhaus (2010) find an increasing trend for normalised damage costs, the remaining studies, except Schmidt *et al.* (2010) and Bahinipati and Venkatachalam (2014), report no observable increasing trend. In fact, both the studies find an increasing trend, but the trend line of the normalised damage costs is flatter than that of the reported economic losses. No trend implies that socio-economic factors are the major cause for increasing damages in the recent years, and increasing trend denotes that factors associated with both socio-economic and climate change are triggering the damages, though the extent of influence may differ (Bahinipati and Venkatachalam, 2014).

3. DATA AND METHODS

There is no unique definition for the term 'economic losses'. The natural hazard literature categorises it in three ways: (i) direct losses, (ii) indirect losses, and (iii) secondary/ consequential losses (Kron *et al.*, 2012). For the present analysis, reported direct economic loss estimates from natural disasters are used in line with the existing normalisation studies (e.g., Raghavan and Rajesh, 2003; Bahinipati and Venkatachalam, 2014)[2]. Accordingly, natural disasters in this chapter consist of biological (i.e., epidemic and insect infestation), climatological (i.e., drought, extreme temperature and wildfire), geophysical (i.e., earthquake and volcano), hydrological (i.e., flood) and meteorological (i.e., cyclonic storm) disasters. Data related to natural disasters in India, e.g., number of events and the economic losses, for the period 1964-2012 are compiled from EM-DAT international disaster database[3]. There is no standard method for estimating economic loss in EM-DAT, and several agencies (e.g., disaster management departments of respective countries) have developed their own methodologies to quantify economic losses in their specific domain. In the simplest manner, the economic damage due to a specific disaster is the total damage value at the moment of the event, i.e., figures are presented in terms of US$ for the year in which the natural disaster occurred. The data on socioeconomic indicators are collected from the Handbook of Indian Economy published by the Reserve Bank of India[4].

In order to adjust the socio-economic conditions in the damages from natural disasters, this chapter has adopted two 'normalisation methods' developed by Pielke and Landsea (1998) and Collins and Lowe (2001), which are stated below (also see Bahinipati and Venkatachalam, 2014).

Model 1:

$$NEL^{P}_{2012.Y} = REL_{Y} \times I_{M} \times IN_{M} \times P_{M}$$

Pielke and Landsea (1998); Pielke et al. (2008)

Model 2:

$$NEL^{H}_{2012.Y} = REL_{Y} \times I_{M} \times IN_{M} \times HH_{M}$$

Collins and Lowe (2001)

where, $NEL^{P}_{2012.Y}$ and $NEL^{H}_{2012.Y}$ are representing economic losses in the Y^{th} year adjusted to socio-economic conditions in 2012; while the former uses population for normalisation, the latter employs number of household – because, using population growth could underestimate the magnitude of impact whose value is lower than the economic value of property at risk (Pielke *et al.*, 2008; *c.f.*, Bahinipati and Venkatachalam, 2014). REL_{Y} refers to the reported economic losses in the Y^{th} year, I_{M} means inflation multiplier, IN_{M} refers to per capita income multiplier, and P_{M} and HH_{M} denote population and household multiplier, respectively. The reported economic loss means the immediate damages aftermath of a disaster, and this has been estimated by the respective government agencies of the state where disaster has occurred; it has been collected from the EM-DAT international disaster database. The estimations of inflation, per-capita income and population multiplier are given in appendix 1 (i.e., equations 1 through 4). In both the models, it is assumed that people/households have not taken any adaptation measures over the years, i.e., all the people, households and infrastructure in the vulnerable regions are equally exposed to the natural disasters. Due to lack of information, most of the normalisation studies are not able to incorporate adaptation in their analysis; the studies by Crompton and McAneney (2008) and Bahinipati and Venkatachalam (2014) are noteworthy exceptions.

4. RESULTS AND DISCUSSIONS

4.1. Reported and Normalised Damage Costs from Natural Disasters in India

The reported and normalised economic losses from natural disasters in India between 1964 and 2012 are presented in Table 2, and the descriptive statistics and period wise damage costs are given in Tables 3 and 4, respectively. It can be observed from these Tables that India has experienced around 545 natural disasters which correspond

Table 2. Reported and Normalised Economics Losses due to Natural Disasters, Floods and Cyclonic Storms during 1964-2012 (US$ in billions)

Year	Natural Disasters			Floods			Cyclonic Storms		
	Reported Economic Loss	Normalised Economic Loss		Reported Economic Loss	Normalised Economic Loss		Reported Economic Loss	Normalised Economic Loss	
		Model 1	Model 2		Model 1	Model 2		Model 1	Model 2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1964	0.001	5.71	6.54	0.001	5.71	6.54	-	-	-
1965	0.100	1,005.54	1,152.58	-	-	-	-	-	-
1966	0.006	43.86	50.25	0.001	10.97	12.56	0.004	32.90	37.68
1967	0.0004	2.45	2.81	-	-	-	-	-	-
1968	0.094	531.76	611.15	0.094	531.76	611.15	-	-	-
1969	0.008	41.62	47.84	-	-	-	0.008	41.62	47.84
1970	0.101	475.15	546.81	0.101	475.15	546.81	-	-	-
1971	0.560	2,349.82	2,711.53	0.530	2,223.94	2,566.27	0.030	125.88	145.26
1972	0.100	345.06	400.42	-	-	-	-	-	-
1975	0.914	1,590.46	1,874.36	0.714	1242.54	1464.33	0.200	347.92	410.03
1976	0.267	405.53	479.65	-	-	-	0.267	405.53	479.65
1977	0.499	620.88	737.87	-	-	-	0.499	620.88	737.87
1978	0.166	189.98	226.75	0.166	189.98	226.75	-	-	-
1979	0.313	287.94	346.00	0.100	92.05	110.61	0.013	11.78	14.16
1980	0.320	219.98	265.61	0.320	219.98	265.61	-	-	-
1981	0.250	133.47	161.38	0.250	133.47	161.38	-	-	-
1982	1.445	639.07	771.94	0.700	309.50	373.84	0.745	329.58	398.10
1983	0.591	204.64	246.48	-	-	-	0.591	204.64	246.48
1984	0.127	36.42	43.78	0.090	25.81	31.02	0.035	10.04	12.06
1985	0.952	230.43	276.33	0.808	195.57	234.53	-	-	-
1986	0.654	132.92	158.94	0.376	76.43	91.40	0.273	55.47	66.33
1987	0.545	89.54	106.86	0.545	89.54	106.86	-	-	-
1988	1.033	131.30	156.29	0.947	120.42	143.35	0.013	1.65	1.97
1990	2.893	228.35	270.12	-	-	-	2.893	228.35	270.12
1991	0.318	19.29	22.73	0.258	15.65	18.44	-	-	-
1992	0.309	15.00	17.58	0.309	15.00	17.58	-	-	-
1993	7.880	297.06	347.58	7.500	282.74	330.81	0.100	3.77	4.41
1994	0.194	5.70	6.65	0.175	5.14	5.99	0.019	0.56	0.65
1995	0.313	7.20	8.35	0.260	5.98	6.94	0.048	1.11	1.29
1996	2.237	40.98	47.29	0.194	3.55	4.10	1.500	27.49	31.72
1997	0.262	4.05	4.65	0.225	3.48	3.99	-	-	-
1998	1.008	12.41	14.18	0.529	6.51	7.44	0.479	5.90	6.74
1999	2.994	32.28	36.66	0.002	0.03	0.03	2.990	32.23	36.60

continued on following page

Table 2. Continued

Year	Natural Disasters			Floods			Cyclonic Storms		
	Reported Economic Loss	Normalised Economic Loss		Reported Economic Loss	Normalised Economic Loss		Reported Economic Loss	Normalised Economic Loss	
		Model 1	Model 2		Model 1	Model 2		Model 1	Model 2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2000	1.496	14.54	16.41	0.908	8.82	9.96	-	-	-
2001	2.985	25.94	29.17	0.362	3.15	3.54	-	-	-
2002	0.962	7.47	8.31	0.051	0.39	0.44	0.0004	0.003	0.004
2003	0.613	4.09	4.51	0.169	1.13	1.24	0.044	0.29	0.32
2004	3.799	21.30	23.27	2.776	15.56	17.00	-	-	-
2005	7.240	34.10	36.90	6.190	29.15	31.54	-	-	-
2006	3.390	12.82	13.73	3.390	12.82	13.73	-	-	-
2007	0.376	1.16	1.22	0.376	1.16	1.22	-	-	-
2008	0.145	0.35	0.37	0.145	0.35	0.37	-	-	-
2009	2.734	5.47	5.66	2.434	4.87	5.04	0.300	0.60	0.62
2010	2.149	3.30	3.38	2.149	3.30	3.38	-	-	-
2011	2.033	2.50	2.53	1.657	2.04	2.06	0.376	0.46	0.47
2012	0.244	0.24	0.24	0.244	0.24	0.24	-	-	-
Max. (Year)	7.880 (1993)	2,349.82 (1971)	2,711.53 (1971)	7.500 (1993)	2,223.94 (1971)	2,566.27 (1971)	2.99 (1999)	620.88 (1977)	737.87 (1977)
Min. (Year)	0.0004 (1967)	0.24 (2012)	0.24 (2012)	0.001 (1964)	0.03 (1999)	0.03 (1999)	0.0004 (2002)	0.003 (2002)	0.004 (2002)

Note: '-' indicates not availability of data or the extreme events may not occur in that particular year.
Source: Authors' computation based on data collected from EM-DAT: The OFDA/CRED International Disaster Database

Table 3. Reported and normalised economic losses from natural disasters in India during 1964-2012 (in US$ billions)

Disaster Type	No. of Events	Avg. No. of Events	Reported Economic Loss		Normalised Economic Loss			
					Model 1		Model 2	
			Total	Avg.	Total	Avg.	Total	Avg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Natural Disasters	545	11	55.62	1.21	10,509.14	228.46	12,303.60	267.47
Floods	223 (40.92)	5	36.05 (64.81)	0.95	6,363.89 (60.56)	167.47	7,438.10 (60.45)	195.74
Cyclonic Storms	134 (24.59)	3	11.43 (20.55)	0.50	2,488.67 (39.11)	108.20	2,950.37 (39.67)	128.28

Note: figures in parentheses indicate percentage
Source: Authors' computation based on data presented in Table 2

Table 4. Period wise Reported and normalised economic losses from natural disasters in India during 1964-2012 (in US$ billions)

Period	Natural Disasters			Floods			Cyclonic Storms		
	Reported Economic Loss	Normalised Economic Loss		Reported Economic Loss	Normalised Economic Loss		Reported Economic Loss	Normalised Economic Loss	
		Model 1	Model 2		Model 1	Model 2		Model 1	Model 2
1964-69	0.21	1,630.95	1,871.15	0.10	548.44	630.25	0.01	74.52	85.52
1970-74	0.76	3,170.03	3,658.76	0.63	2,699.09	3113.08	0.03	125.88	145.26
1975-79	2.16	3,094.80	3,664.62	0.98	1,524.57	1801.69	0.98	1,386.12	1,641.70
1980-84	2.73	1,233.59	1,489.18	1.36	688.76	831.85	1.37	544.25	656.64
1985-89	3.18	584.18	698.41	2.68	481.97	576.13	0.29	57.12	68.29
1990-94	11.59	565.41	664.65	8.24	318.53	372.83	3.01	232.68	275.18
1995-99	6.81	96.91	111.12	1.21	19.55	22.50	5.02	66.72	76.35
2000-04	9.85	73.33	81.66	4.27	29.05	32.18	0.04	0.30	0.33
2005-09	13.89	53.89	57.88	12.54	48.35	51.91	0.30	0.60	0.62
2010-12	4.43	6.04	6.15	4.05	5.58	5.68	0.38	0.46	0.47

Source: Authors' computation based on data presented in Table 2

to an average of 11 disasters per annum. Out of these events, the incidences (frequency) of floods have been reported for 223 times (i.e., 41%) and cyclonic storms for 134 times (i.e., 25%). Further, India has encountered an economic loss of US$ 55.62 billion from natural disasters during 1964-2012 (column 4 in Table 3), which is around US$ 1.21 billion per year during the same reference period (column 5 in Table 3). While floods inflicted a total damage cost of US$ 36.05 billion (65%), around US$ 11.43 billion (21%) was due to cyclonic storms (column 4 in Table 3). Therefore, floods and cyclonic storms are the major disasters in India as they account for about 66% of the total number of disasters and 86% of the total reported damage costs. Given this, the chapter also undertakes the normalisation exercise for these two extreme events separately. While adjusting these reported damage cost figures with socio-economic conditions of the year 2012, the total damage costs from natural disasters are higher as compared to the reported, and the similar type of results are also observed in the case of individual disasters like floods and storms (columns 6 and 8 in Table 3).

Figures 3 through 11 present the reported and the normalised damage costs of natural disasters, and individual events like floods and cyclonic storms, respectively. Overall, an increasing trend is observed for the reported economic costs (Figures 3, 6 and 9), which shows that the impacts from natural disasters have been increasing overtime. From this, it may be generally concluded that the bio-physical factors (i.e., climate change, natural climate variability, geo-physical, etc.) have played an instrumental role in raising the economic losses due to natural disasters in the recent years. However, when the reported impact figures are normalised to remove the influence of socio-economic factors, it is found that a decreasing trend exists for the normalised impact from natural disasters (Figures 4 and 5). Similar results are also observed if the normalisation exercise is undertaken for individual events like floods

Figure 3. Reported economic loss from natural disasters
Source: Based on data presented in Table 2

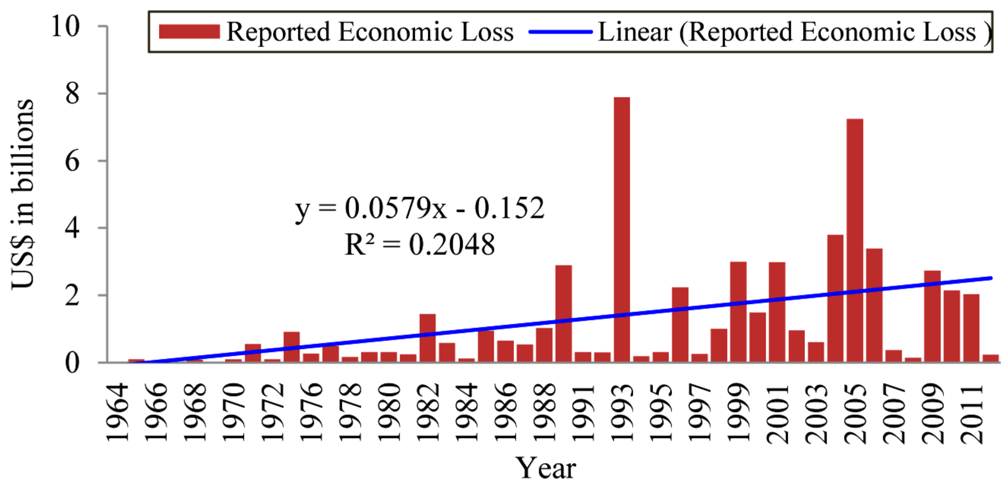
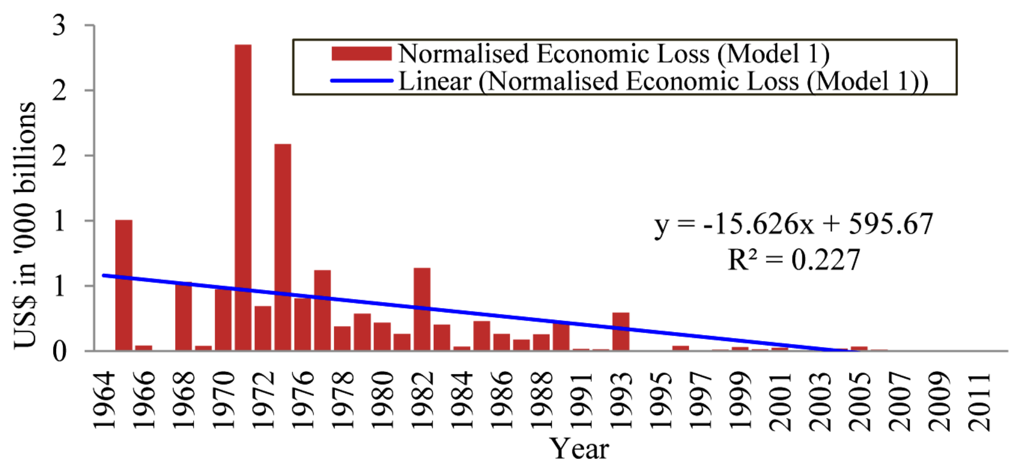


Figure 4. Normalised economic loss from natural disasters (Model 1)
Source: Based on data presented in Table 2



(Figures 7 and 8) and cyclonic storms (Figures 10 and 11). This is in line with the findings from other studies, which also report a no significant trend in the case of normalised economic damages for different regions and provinces (Pielke and Landsea, 1998; Raghavan and Rajesh, 2003; Schmidt *et al.*, 2009; Barredo 2009 and 2010; see Bouwer, 2011).

Further, it is observed from Table 2 that the maximum reported economic damages occur during the 1990s. But, in the case of normalised economic damages (both in models 1 and 2), the maximum economic damages were found for the years during 1970s (see table 1). Similarly, it is observed from Table 4 that the reported damage costs from natural disasters, flood and cyclonic

Figure 5. Normalised economic loss from natural disasters (Model 2)
Source: Based on data presented in Table 2

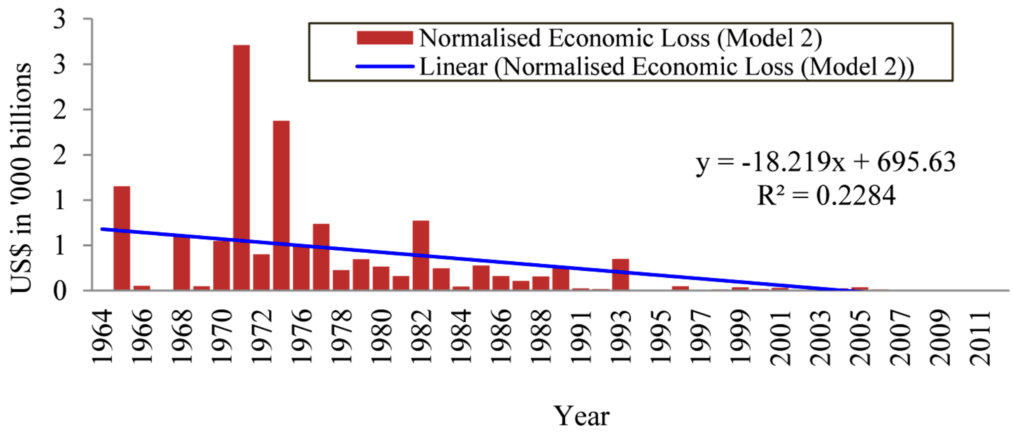
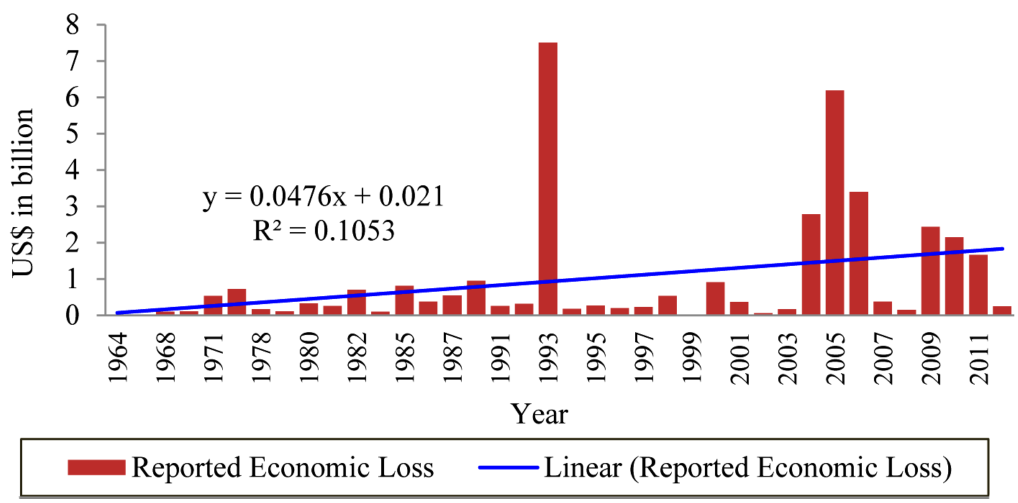


Figure 6. Reported economic loss from floods
Source: Based on data presented in Table 2



storms were higher during the 2000s and in the last decade. While the reported damage costs are normalised by adjusting for the socio-economic conditions for the year 2012, a higher damage costs were found during 1970s and 1980s. In view of these findings, it can be concluded that the increasing trend of damages in the recent decades in India is mostly due to socio-economic factors, i.e., the exposure and vulnerability of wealth and the population living in the disaster prone regions were increasing, and hence, losses tend to be higher even during a low intensity disaster.

4.2. Regional Disaggregation of Damages and the Economic Costs

It is important that the intensity of events and the related economic costs of the damages as presented at the national level would have significant implications for policies and interventions if the impacts

Figure 7. Normalised economic loss from floods (Model 1)
Source: Based on data presented in Table 2

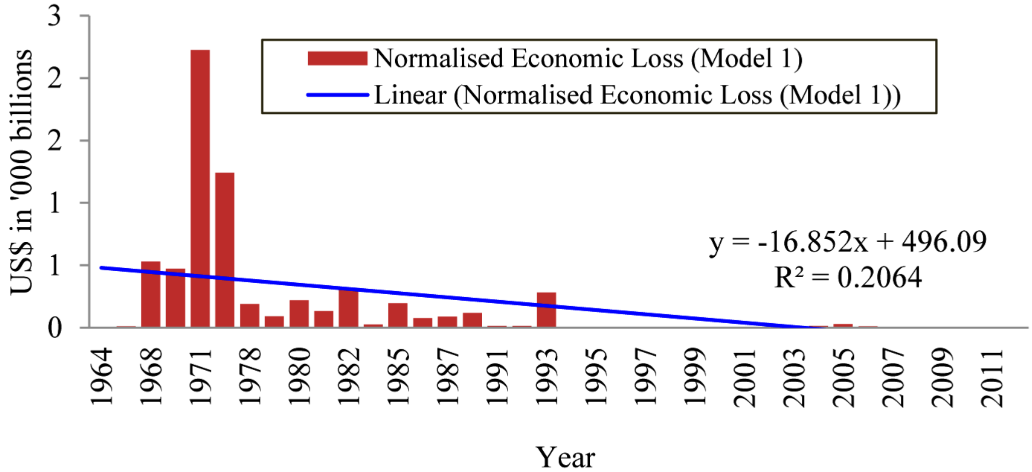
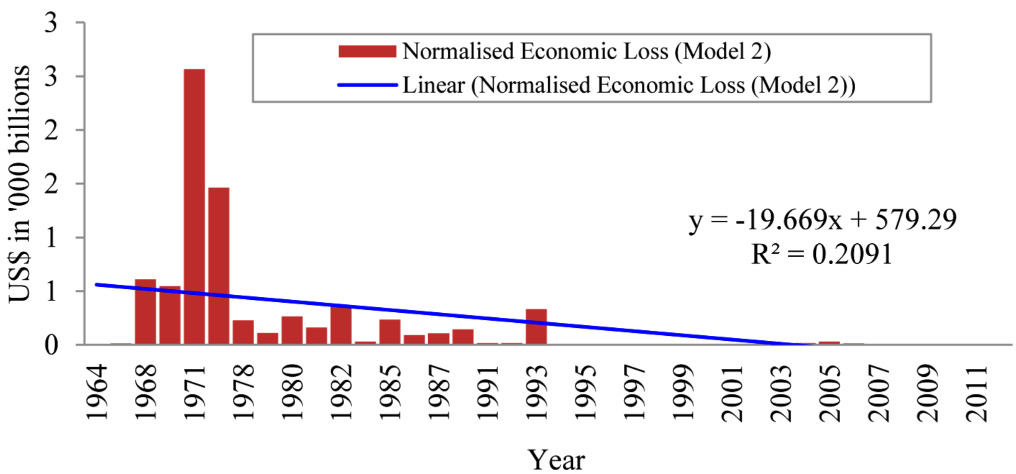


Figure 8. Normalised economic loss from floods (Model 2)
Source: Based on data presented in Table 2



of the natural hazards are analysed in terms of their regional spread and intensity. However, a clear depiction of the regional pattern of the spread and intensity of the various types of natural disasters is beyond the scope of the present analysis in view of the absence of disaggregate level time-series data on these events and their economic dimensions. Based on a cursory look at the cumulative data on the damages caused by floods (expressed as people affected, human lives lost and the total damage cost) as compiled by from the data source available at the Central Water Commission[5] are presented in Table 5.

It may be observed from Table 5 that though the all the 12 states have been affected by the flood damages, the severity of the impacts in terms of people affected and the loss of lives have been mostly confined to eight states. For instance, five

Figure 9. Reported economic loss from cyclonic storms
Source: Based on data presented in Table 2

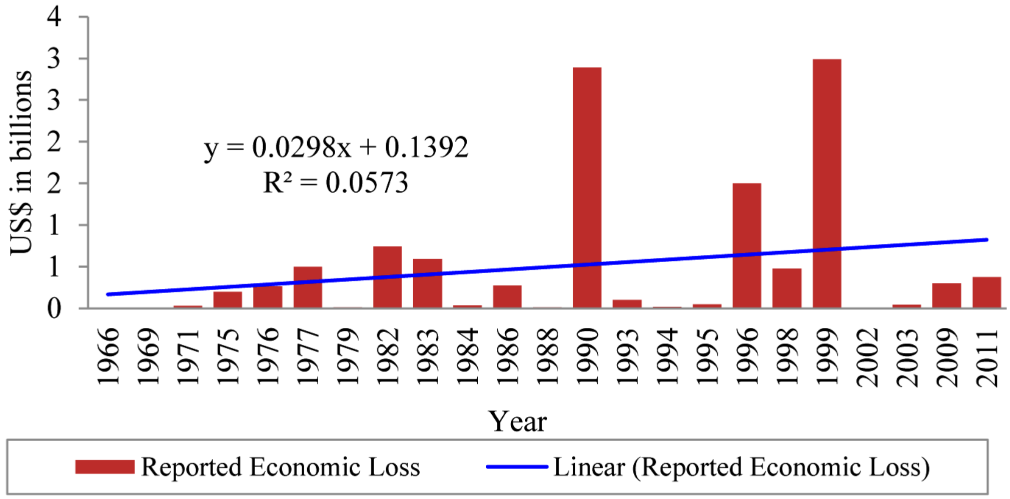
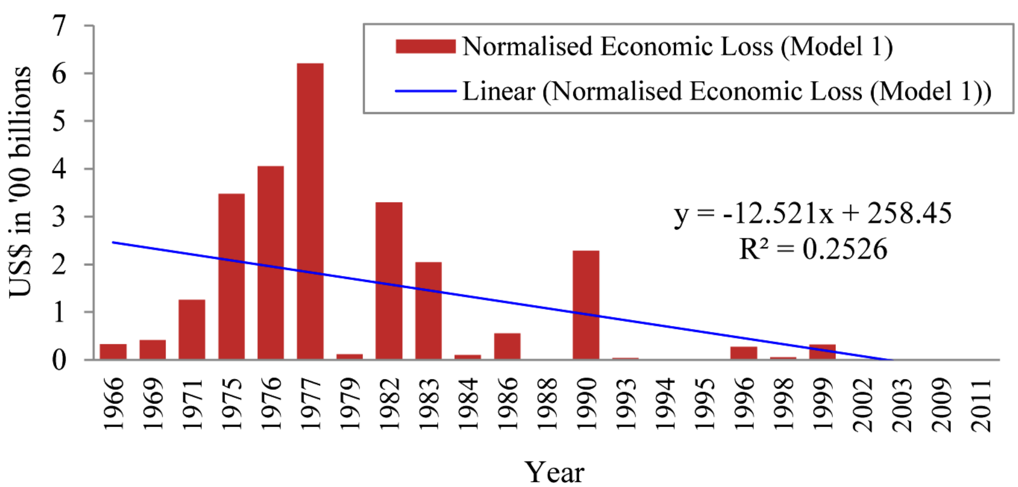


Figure 10. Normalised economic loss from cyclonic storms (Model 1)
Source: Based on data presented in Table 2



states, namely, Uttar Pradesh, Bihar, West Bengal, Assam and Odisha together accounted for almost 70% of the total number of people affected. In terms of loss of lives, five states, namely, Uttar Pradesh, Andhra Pradesh, Bihar, West Bengal and Gujarat together accounted for 64% of the total human casualties at the national level. Further, in terms of the cumulative economic costs of the damages reported, five states, viz., Andhra Pradesh, Karnataka, Uttar Pradesh, West Bengal and Odisha together accounted for almost 66% of the total damage costs at the national level.

Though constrained by data availability, the above analysis on the intensity and the economic

Figure 11. Normalised economic loss from cyclonic storms (Model 2)
Source: Based on data presented in Table 2

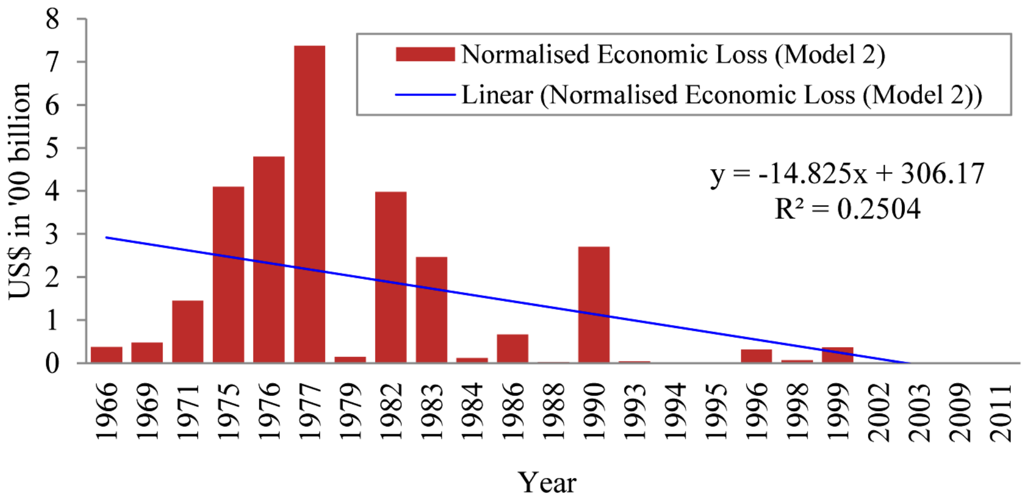


Table 5. State wise damage statistics due to Floods in India (1953-2011)

State/Country	Total People Affected (Million)	% Share	Average People Affected (Million)	Total No. of Lives Lost	% Share	Average No. of Lives Lost	Total Damage Cost (Rs. Million)	% Share
Andhra Pradesh	117.5	6.1	3.16	16,655	17.1	354	5,57,780	26.2
Arunachal Pradesh	11.8	0.6	0.47	455	0.5	23	1,15,351	5.4
Assam	163.4	8.5	2.77	2,753	2.8	47	46,594.7	2.2
Bihar	387.5	20.3	6.67	9,909	10.2	178	1,36,952	6.4
Gujarat	92.2	4.8	1.81	8,557	8.8	175	56,120.3	2.6
Himachal Pradesh	35.1	1.8	1.25	2,398	2.5	52	1,22,622	5.8
Karnataka	30.3	1.6	0.87	2,541	2.6	62	3,19,678	15.0
Kerala	81.7	4.3	1.74	3,350	3.4	67	69,356.7	3.3
Odisha	154.5	8.1	3.09	2,291	2.3	50	1,59,853	7.5
Rajasthan	33.0	1.7	0.79	2,652	2.7	56	71,278.2	3.3
Uttar Pradesh	406.3	21.2	6.89	17,775	18.2	301	1,91,789	9.0
West Bengal	229.3	12.0	4.09	9,912	10.2	191	1,71,824	8.1
India	1913.4	100	32.43	97551	100	1653	2131149	100

Note: The figures, including the damage costs, are cumulative numbers as reported by the States, and we have not adjusted the damage costs figure with respect to inflation.

Source: Compiled from data available at the Central Water Commission (see footnote 5)

cost dimensions of the floods are certainly indicative of the severity of the natural damages across the major states that are increasingly becoming vulnerable to the different events, especially, floods. Nevertheless, it is important that such analysis is critical with respect to other natural hazards, especially, cyclonic storms, in order to understand the regional patterns, severity and frequency of the events across the states. This is an important area needing further assessment based on longitudinal data and empirical analysis. However, there exists a huge data gap at the disaggregate level for many of the critical parameters on the incidence of various climate change induced natural disasters.

5. CONCLUDING OBSERVATIONS AND POLICY SUGGESTIONS

By normalising the reported economic losses from natural disasters, this chapter provides better estimates for the economic losses due to these events in India. Our analysis suggests an increasing trend for the reported economic loss from natural disasters as well as individual extreme events like floods and storms, whereas a declining trend is observed if the damage costs are normalised. This suggests that the observed increase in damages from natural disasters is mainly due to socio-economic factors, i.e., inflation, growth of population, wealth and income. Therefore, from a policy perspective, the findings from the study highlight the need for reducing the potential impacts from natural disasters in the foreseeable future. This in turn, calls for increased investments in infrastructure for enhancing the resilience and adaptive capacity of the vulnerable communities/regions. Nevertheless, the findings of this study could be affected firstly, by reporting bias about damages from natural disasters and spatial variation of the socio-economic factors. Secondly, the analysis has not considered adaptation measures undertaken at institutional and household levels. Still, it underscores the importance of long-term assessment of the behaviour of climatic change events as well as the policy and institutional responses in region-specific contexts. Such assessments can yield more robust results with respect to the resilience and adaptive capacities of the climatic risk prone communities and regions.

The results of this study do need to be interpreted with some caution, with regards to three aspects. First, there is an underlining assumption that individual households and governments have not taken any adaptation measures over the years. However, various studies find that adaptation options are being undertaken to mitigate possible impacts of climate extremes in India (Raghavan and Rajesh, 2003; Patnaik, 2009; Nambi and Bahinipati, 2012; Bahinipati and Venkatachalam, 2013 and 2014; Bahinipati, 2014; Patnaik and Narayanan, 2014; Bahinipati and Patnaik, 2015; Nambi et al., 2015). Second, the findings of this study could be affected by reporting bias, i.e., there is a high chance of under reporting of damage costs for earlier years due to lack of proper reporting, data collection and or documenting systems in place. Third, the present analysis has not taken into account other crucial factors such as indirect damages, non-market damages, spatial variation, disaster specific adaptation measures, etc.

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ENDNOTES

1 This period is being selected because of consistent availability of information on 'economic costs due to natural disasters'.

2 A few studies use insured losses figure wherever this data is available (e.g., see Neumayer and Barthel, 2011).

3 The OFDA/CRED International Disaster Database – www.emdat.be - Université Catholique de Louvain, Brussels, Belgium; accessed on 5th July 2014. For a disaster to be entered into this database should satisfy one of the criteria, such as: (i) ten or more people reported killed; (ii) hundred or more people reported affected; (iii) declaration of a state of emergency; and (iv) call for international assistance.

4 http://www.rbi.org.in/scripts/AnnualPublications.aspx?head=Handbook%20of%20Statistics%20on%20Indian%20Economy; accessed on 10th July 2014.

5 These information have been gathered from 'State wise Flood Damage Statistics' provided by Central Water Commission, Government of India, New Delhi, Vide Letter No. 3/38/2011-FFM/2200-2291 dated: 27th November 2012.

APPENDIX

$$I_M = \left(\frac{PCNDPFCCU_{2012}}{PCNDPFCCO_{2012}} \right) \Big/ \left(\frac{PCNDPFCCU_Y}{PCNDPFCCO_Y} \right) \quad (1)$$

$$IN_M = \frac{PCNDPFCCO_{2012}}{PCNDPFCCO_Y} \quad (2)$$

$$P_M = \frac{P_{2012}}{P_Y} \quad (3)$$

$$HH_M = \frac{HH_{2012}}{HH_Y} \quad (4)$$

where,

$PCNDPFCCU_{2012}$ = Per Capita Net Domestic Product Factor Cost at Current price in the year 2012;
$PCNDPFCCO_{2012}$ = Per Capita Net Domestic Product Factor Cost at Constant price in the year 2012;
$PCNDPFCCU_Y$ = Per Capita Net Domestic Product Factor Cost at Current price in the Y^{th} year;
$PCNDPFCCO_Y$ = Per Capita Net Domestic Product Factor Cost at Constant price in the Y^{th} year;
P_{2012} = Population in the year 2012;
P_Y = Population in the Y^{th} year;
HH_{2012} = Number of households in the year 2012; and
HH_Y = Number of households in the Y^{th} year.

Chapter 9
Evolution and Efficacy of Drought Management Policies and Programmes:
The Case of Western Odisha, India

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ABSTRACT

The paper analyses the major role played by the institutional support system such as government safety nets, non-governmental and community based insurance mechanism in strengthening the coping capacity of rural households facing recurrent drought in Bolangir district of western Odisha. The gradual refinement of drought management policies and the role played by centre-state relationship and power equations in implementation of programmes for effective drought management have been critically examined. In addition to analysis of secondary data and literature, the primary survey data on 139 households have been analyzed to assess the role of institutional support system in building up their resilience. The institutional support system was found to be weak to withstand drought in effective manner in the study region. A gradual improvement to the drought management policies was observed and every major drought resulted in some qualitative improvement to the relief approach. However, the implementation of the development schemes was affected by the power politics.

INTRODUCTION

Drought is a slow onset natural calamity that affects more people concurrently than any other weather hazard. The impacts of drought on rural livelihood and agrarian economy are diverse and complex. Drought results in extensive damage to crops and hydrological imbalances affecting different livelihood activities directly or indirectly. The rural households and their income generation activities exhibit a great deal of sensitivity to different drought risk factors such as insufficient

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and/or erratic rainfall, fodder unavailability, lower water table and less irrigation coverage. Their income, expenditure and savings and access to water resources are significantly affected. They endure several hardships on account of consumption shortfall and health related problems (Swain, 2010). To cope with the adverse effects and to reduce the level of their vulnerability, they adopt different strategies[1]. However, drought is primarily a covariate risk and mitigating drought risks at individual level is a distant reality because of the fact that the cost of mitigation measures is relatively higher than the financial strength of majority of rural households in drought prone region where poverty and backwardness are common phenomena. Mitigating drought risks requires a multi-pronged attack with a participatory approach that requires institutional support (Pattnaik, 1998; GOI, 2010).

Government has an important role to play in terms of promotion of community-based disaster mitigation measures such as development and renovation of community based water harvesting structures (WHSs), developing common property resource base, strengthening rural socio-economic infrastructure like education, health and financial institutions etc. and supporting the long-term income and crop diversification process. There have been marked improvements over the years in government's approach to mitigate drought both in terms of policy formulation and action (Samal et al, 2003). However, the steps taken so far are not enough for mitigating the drought risks. Agarwal (2000) says it is possible to banish drought completely within a decade if government applies its mind. Thus the institutional approach to drought management needs to be refined further.

In this context, the study analyses the factors that led to gradual refinement of drought management policies and programmes with special reference to western Odisha. The role played by centre-state relationship and power equations in implementation of programmes for drought management has been critically examined. Finally, the major role played by the institutional support system such as government safety nets, non-governmental and community based insurance mechanism in mitigating the drought risk and vulnerability has been assessed in the context of Bolangir district of western Odisha.

The present paper is presented in seven sections. Next section discusses about the study area, data and methodology. The 3rd section briefly analyses the nature of drought vulnerability in the study region. The 4th section presents an account of gradual refinement of drought management policies that affected the study region. The 5th section critically analyses the political economy of drought. The 6th section examines the role of institutional support system in building households' resilience to drought in the study region. The 7th section concludes with some policy suggestions.

STUDY AREA, DATA AND METHODOLOGY

Bolangir district is one of the constituent districts of the undivided KBK (Kalahandi-Bolangir-Koraput) region in western Odisha[2], which has been at the limelight for prevalence of chronic poverty, malnutrition, hunger and starvation death and periodic out migration (Pattnaik, 1998). The geographical area of the district is 6,575 sq. km, and has a population of about 1.38 million (GOI, 2001). The proportion of rural population is much higher (88.46%) in the district and so also in the entire KBK region (about 90%). The proportion of scheduled castes (SCs) and scheduled tribe (STs) in total population was around 16.9 percent and 20.6 percent respectively. About 2.01 lakh families comprising 61.1 per cent of total are below the poverty line (BPL) in the district as per BPL survey conducted in 1997 (GOO, 2002). The district also suffers from acute economic, social and gender disparities, and very adverse socioeconomic and human development indicators. Agriculture is the predominant source of livelihood for the people in the district. About 52.7 per cent of total main workers are agricultural labourer in the district (GOI, 2001). The district has been affected by droughts of different intensities in twenty out of last fifty years (1962-63 to 2011-12). The district including other districts of KBK region is almost at the bottom of the list of 250 Backward Districts identified by the Government of India for consideration of grant under Backward Regions Grant Fund (BRGF). The long-term and holistic development strategies are essentially required to bring this region closer to the other developed regions in the country.

The study is based on both secondary and primary data. The secondary data on irrigation coverage, crop insurance and funds flow for drought management etc. were analyzed. In this study we used a purposive multi-stage stratified sampling method to select 139 sample households. At the first stage, we purposively selected Bolangir district of western Odisha as it is the most vulnerable to drought among all the thirty districts of Odisha (Roy *et al.* 2004). The entire district has been declared as the drought prone by the Government of India. In the second stage, we selected three blocks Saintala (most vulnerable), Patnagarh (moderately vulnerable), and Titlagarh (least vulnerable) on the basis of degree of drought vulnerability[3]. In the third stage, three villages, one from each of the identified blocks, were selected purposively considering their suitability for the study purpose and the degree of their representation for their respective districts in terms of socio-economic and biophysical factors. Finally, households (HHs) were sampled and chosen from each of the selected villages using a stratified random sampling approach covering twelve major livelihood groups[4]. The reference year for the household survey was 2002 during which severe drought had affected the entire study region.

In this study, institutional support system includes a network of organizations (governmental, non-governmental and community based) that supported drought affected rural households in reducing or mitigating their risks and securing their livelihoods through generation of income, employment and assets. The detailed institutional arrangement to manage drought at different levels have been presented in Appendix I.

NATURE OF DROUGHT VULNERABILITY IN BOLANGIR

Drought is a recurring and single most insidious phenomenon in Bolangir district of western Odisha. The recurrent drought phenomenon in the region is mostly responsible for its 'chronic backwardness' and widespread seasonal outmigration (Pattnaik, 1998). The increasing frequency of occurrence of the hazard is one of the major factors behind the rising level of drought vulnerability in the region, which is mainly due to larger variability in rainfall from season to season, rather than deficiency in amount of annual rainfall (Sainath, 1996; Swain, 2006). Another major factor for increasing drought frequency and vulnerability in Bolangir is the low irrigation coverage and neglect of the traditional water-harvesting structures (Nayak, 2004; Roy et al., 2004). The irrigation coverage in the district hovers around 23 per cent and the major sources of irrigation are dug wells and other water-harvesting structures (Swain et al., 2009). Nearly four decades ago, water-harvesting structures (WHSs) built with community participation were irrigating about 33 per cent of cultivated lands in the area. But the conditions of these WHSs gradually deteriorated due to lack of maintenance and proper upkeep. This increased the drought vulnerability as there was no expansion of irrigation in the area to compensate the loss of irrigated area due to abandon of the WHSs. Moreover, the forest cover of about 40 per cent during 1940s declined to about 20 per cent during 1960s. At present, forest cover is just about 14.5 per cent. The lower forest coverage also resulted in frequent rainfall aberrations. The disappearance of drought-resistant indigenous crop varieties due to promotion of HYVs has also aggravated the drought situation in Bolangir. In the early 1960s, there were as many as 300 varieties of paddy seeds, which the farmers were cultivating and most of them were highly drought resistant. When some varieties were failing to adjust with moisture stress, some other varieties were escaping the drought impacts. As a result, farmers were able to harvest a reasonable amount of crop output. However, the number of paddy varieties decreased to just 71 in the year 1996 that raised the level of their vulnerability (Roy et al., 2004). Among farmer communities, the small and marginal farmers were found to be more vulnerable compared to large and medium farmers due to their low level of coping capacity due to poor resource base, limited access to credit and insurance, inadequate safety net provisioning (Swain and Swain, 2009). Hence, the low irrigation coverage along with neglect of traditional WHSs, misuse and over exploitation of natural resources like forests and minerals and the depreciation of agro-biodiversity in the region, chronic and mass poverty and inadequate institutional support are major causes of the rising levels of drought vulnerability in the region. We can thus say that it is largely human induced factors that seem to exacerbate the vulnerability to drought in the region.

GRADUAL REFINEMENT OF DROUGHT MANAGEMENT POLICIES

It is essential that the existing policies be refined on the basis of past experiences so as to enhance institutional efficiency and manage recurrent drought more effectively. Examining the drought management policies over a long period of time reveals that there has been a noticeable improvement to the approach of famine and drought management and every major drought/famine has brought about some qualitative improvement to the relief approach. Though, there has been improvement in policy approach, the development programmes have not been implemented properly and they are found to reach a very small section of the target groups (see Table 1).

The frequency of occurrence of droughts was less during 18th and 19th century over 20th century. However, the intensity of scarcity and famine conditions was more severe (Bhatta, 1997). Particularly, the occurrence of great famine of 1866 in Odisha along with parts of Bengal, Bihar and Madras led the British Government to appoint the first Famine Commission in 1880, which suggested for providing of employment to the affected persons on the public works, extension of irrigation and improved methods of agriculture, improvement in communication and establishment of famine insurance fund to meet the expenditure on relief works. The 2nd Famine commission (1898), mainly

Table 1. Provision of Funds for Drought Mitigation Measures in Odisha and Bolangir during 2002-03 (Rs lakh)

Sl. No.	Measures	Bolangir	% of State Total	Odisha
	Labour Intensive Works			
1	(a) Grain (MT)	14211.00	3.37	422000.00
	(b) Cash	356.25	4.30	8276.58
		(80.47)		(76.54)
2	Protective Irrigation	8.00	3.86	207.00
		(1.81)		(1.91)
3	Revival of LI points	33.00	4.03	818.21
		(7.45)		(7.57)
4	GR in kind	5.00	5.26	95.00
		(1.13)		(0.88)
5	TC for food grains	36.96	3.45	1071.09
		(8.35)		(9.91)
6	Emergency Feeding Programme	3.48	1.01	345.44
		(0.79)		(3.19)
	Total	442.69	4.09	10813.32
		(100.00)		(100.00)

Note: Figures in parentheses are percentages of total. GR implies Gratuitous Relief and TC stands for transport charges

Source: GOI (2003).

recommended suspension and diminution of land revenue and payment of wages to the persons engaged in the public works subject to a minimum and a maximum daily wage. The 3rd Famine Commission (1989) emphasized the need of having a well-designed relief plan in advance of drought including the mitigation programmes. The commission recommended cultivation of fodder crops, grant of loan, opening of cattle camps and relief to aged and destitute (Samal et al, 2003). After independence, the word "famine" was replaced by the word "scarcity" and the famine relief codes of the erstwhile provinces (including Odisha) were replaced by the 'scarcity relief manuals', which describe scarcity as a marked deterioration in crop production due to rainfall deficiency, floods and crop damage due to pest attack resulting in severe unemployment and consequent distress among the agricultural labourers and small cultivators. The Odisha Relief Code (ORC) was the only disaster policy document in Odisha that contained the detailed norms for relief measures to be undertaken during or just after the occurrence of drought (GOO, 1990).

The qualitative improvements in drought management policy were observed with occurrence of every major drought. The severe drought of 1965-66 contributed to building up of reliable public distribution system to ensure food security to drought affected people. The periodic occurrence of drought during 1972, 1974 and 1976 forced the government to focus on the need for evolving massive employment generation programme with a view to enhancing the purchasing power of the people instead of providing subsidies and free ration to the affected population. This resulted in starting of Food for Work (FFW) programme in 1977. The drought of 1979 prompted the government to emphasize the need for creating durable community assets for enabling the people of the affected area to withstand future droughts with greater resilience. This gave rise to National Rural Employment Programme (NREP) and Integrated Rural Development Programme (IRDP) in 1980. The consecutive drought of 1980, 1981 and 1982 resulted in kicking off the Rural Landless Employment Guarantee Programme (RLEGP) in 1983. Under NREP and RLEGP programmes, foodgrains were given to workers as a part of the wage component of the programme that aimed at providing food security to rural poor during drought situations. These two programmes were later merged to form *Jawahar Rojagar Yojana* (JRY)[5] in 1989 on 80:20 cost sharing basis between the Centre and the States. During drought period of 1987-88, the self-employment programmes namely, Integrated Rural Development Programme (IRDP)[6], Development of Women and Children in Rural Area (DWCRA), Training of Rural Youth for Self-Employment (TRYSEM)[7] were in operation which aimed at improving the economic condition of below poverty line (BPL) households by arranging productive economic ventures for them through a mix of bank credit and government subsidy (GOI, 2002). JRY, IRDP and TRYSEM were merged to form a new self-employment programme called Swarna Jayanti Gram Swarojgar Yojana (SGSY)[8] with effect from 1st April 1999. In order to provide wage employment to rural poor, another scheme called Employment Assurance Scheme (EAS) was launched on 2nd October, 1993 in 1775 identified backward blocks situated in drought prone, desert, tribal and hilly areas of the country including the study district. The scheme provided about 100 days of assured casual manual employment during the lean agricultural season, at statutory minimum wages to employment seekers. In spite of implementation of a number of programmes during the 1980s and 1990s, the people in the study area suffered a lot due to frequent droughts throughout 1980s and 1990s.

Besides these developmental programmes, some long-term programmes were taken up by the government specifically for drought proofing among which Drought Prone Area Programme (DPAP) was a major one that was initiated in 1970-71. The programme aimed at gradual mitigation of drought impacts through an integrated development of the area by the adoption of appropriate technologies so as to promote overall economic development and improving the socio-economic conditions of the resource poor and disadvantaged sections inhabiting in the programme areas. The emphasis under the programme was on soil and water conservation, land shaping, afforestation and pasture development. These inter-related programmes together affected favorably to the environment. The programme is in operation in 47 blocks of eight districts of Odisha including the study district (Bolangir). Another programme called Desert Development Progamme (DDP) was started in the year 1977-78 covering over 227 development blocks of 36 districts in seven states (Andhra Pradesh, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka and Rajasthan) of the country. These two programmes (DPAP and DDP) were reviewed by *Hanumanta Rao Commttee* (GOI, 1994). The committee recommended a new criterion to identify the drought prone blocks based on a Moisture Index. It recommended to adopt a watershed approach to treat land and water resources of a region for fueling all-round development with appropriate land use pattern encompassing cultivation of major crops, horticulture, fodder, fuel wood and social forestry. The recommendations of the committee were accepted by the government.

After a decade of review by *Hanumantha Rao Committee*, the government constituted another technical committee named *Parthasarathy Committee on DPAP, DDP and IWDP* (GOI, 2006) to review the watershed programmes and to address the issues highlighted in the impact assessment studies and to reassess the criteria of moisture index and re-identify the blocks under DPAP/ DDP for biotic and climatic changes during the period. The major recommendations by the Committee in the context of Odisha were (i) to merge National Watershed Development Programme (NWDPRA), DPAP and Integrated Wasteland Development Programme (IWDP) to form one programme; (ii) to emphasize community mobilization, impact assessment and monitoring processes on a regular basis and (iii) to promote livelihood focused watershed programme as the next generation Watershed Development (WSD) programme.

As far as the Kalahandi-Bolangir-Koraput (KBK) region in western Odisha is concerned, a good number of special programmes have been implemented in the region for drought mitigation and poverty reduction. Since poverty level was acute during 1980s in the region, the Area Development Approach for Poverty Termination (ADAPT) programme was launched in Kalahandi-Bolangir-Koraput (KBK) region in 1988. Due to growing emphasis on long-term programme with participatory approach, a Long Term Action Plan (LTAP) for the three undivided districts of KBK was prepared in 1993 in consultation with the Central Government. The LTAP was conceptualized for a period of seven years from 1995-96 to 2001-02 with two objectives in view: (a) drought and distress proofing, and (b) poverty alleviation and development saturation. After a review in 1997-98, the State Government prepared a Revised Long Term Action Plan (RLTAP) which was envisaged for a period of nine years from 1998-99 to 2006-07 with an outlay of Rs 6251.06 crore. The institutional arrangement for implementation of the project was also strengthened[9]. The KBK region has been receiving Special Central Assistance (SCA) of Rs.250 crore per year under RLTAP. Since 12th Five Year Plan, the SCA has been restructured for the region. Under the modified system, the eight districts of the KBK region are getting Rs 120 crore from the Backward Regions Grant Fund (BRGF) and a grant of Rs 130 crore under special plan for KBK.

Funds under the KBK programmes such as BRGF and RLATP are normally utilized to take up various programmes including watershed development, emergency feeding, tribal education, rural electrification and road connectivity. However, the implementation of these programmes has been affected because of the delay in the release of funds by the Central Government (Indian Express, 2013). The Planning Commission had granted Rs 187 crore out of Rs 250-crore proposals for 2012-13, but there was delay in the release of entire amount by the Centre. During 2011-12, Centre had released Rs 130 crore out of sanctioned amount of Rs 250 crore resulting in curtailment of required investments. Odisha government had formulated an eight-year perspective plan for the KBK districts from 2009-10 to 2016-17 with a projected outlay of Rs 4,550 crore and the submitted proposal for the special package is also yet to be approved by the Centre.

For maintaining the momentum gathered under the Revised Long Term Action Plan (RLTAP) and up-scaling the public investment in the Koraput-Bolangir-Kalahandi (KBK) region, the State Government have launched a new initiative, called the Biju KBK Plan under the State Plan over a period of five years effective since 2007-08. The Plan envisaged to take care of those critical gaps which are left uncovered under the BRGF. The State Government allocated Rs.120 crore each year for operation of the programme. But the execution of the programme has not been satisfactory due to administrative negligence (Dash, 2012). The funds have not been utilized to the desirable extent during a period of 2007-08 to 2012-13. The funds utilization in Bolangir, Koraput, Kalahandi, Rayagada, Nowrangpur and Malkanagiri was 63.1 per cent, 63.4 per cent, 57.4 per cent, 60.8 per cent and 80.3 per cent respectively during the corresponding period. The State Government has also made a provision of Rs 192.2 crore for implementation of Special Development Programme and Rs 40 crore under the Special Problem Fund during 2013-14. Besides, Rs 540 crore was proposed for implementation of Integrated Action Plan (IAP) in tribal and backward districts during the corresponding year.

In order to reduce the widening regional disparity between western Odisha districts and coastal districts and to accelerate growth in backward districts in western Odisha, the Western Odisha Development Council (WODC) was constituted under the Western Odisha Development Council Act, 1998 for undertaking developmental activates in 10 western Odisha districts[10]. Different projects under roads and communication, minor irrigation, construction of check dams, installation of lift irrigation points, water supply schemes, sinking of tube wells, infrastructure grants to schools and colleges, rural electrification, assistance to urban local bodies for developmental works etc. have been taken up by the Council. However, its performance over the years has been poor. It came out to fore that frequent changes in the projects by the MLAs and members of the WODC is one of the causes of low spending. Secondly, in the districts where Collectors showed keen interests, the spending was on a higher side. Thirdly, due to lack of coordination between the executing agencies, the spending rate was also affected (Anonymous, 2011).

Two issues have emerged from the preceding discussions. First, the region has not received enough attention of Central Government over the years that has resulted in inadequate and delayed flow of funds to the region. Secondly, whatever funds have been received, the timely utilization of these funds on the targeted activities in an effective manner has not happened. There has not been tangible change in the poverty stricken western Odisha even if huge money has been injected into it over a long period of time.

Even though the drought management policies have been refined over the years and a large number of programmes have been introduced, it is imperative to examine the coverage and efficacy of these policies and programmes in development of these backward regions and in benefitting the lower strata of the society in these regions. It is equally important to examine the reasons behind the delay in funds flow or the sanction of inadequate funds or favoritism in funds sanctions. The next two sections address these issues in detail.

POLITICAL ECONOMY OF DROUGHT

As revealed from the preceding discussions, the government policies and programmes for reducing drought risk have been refined with the experiences of successive droughts so as to enhance the effectiveness of the drought management programmes. However, the institutional performance in allocating resources and implementing the developmental programmes is observed to be influenced by a number of factors. The nature of centre-state relationship and influence of pressure groups have played a key role in the sanction of funds and implementation of the programme. Different forms of public action like research, media, judicial action and social activists have definitely influenced the government actions during calamity period. As Khera (2006) noted the provision of drought relief is a matter of political survival because of the fact that the governments of different political affiliation have to face the electorate every five years and, to that extent, can be punished or rewarded for their performance.

The institutional arrangement for allocation of relief funds requires the coordination between different departments and between governments at the centre and in the state. The coordination between the political parties in power is seen to be affected by different forms of conflicts among them. Such conflicts may be of two kinds, viz., vertical conflicts and horizontal conflicts. The vertical conflicts imply the conflicts between the governments of different political affiliations in successive periods. If a government starts a set of developmental programmes, the same set of programmes may not be allowed to operate by the next government of different political affiliation. On the other hand, with the horizontal conflicts, the governments of different political affiliation at the Centre and in the State may not cooperate each other in the matter of formulation and implementation of different developmental programmes. Unfortunately, the state of Odisha, being the disaster capital of India, has been experiencing both kinds of conflicts over the years. As an example of vertical conflict, the Area Development Approach for Poverty Termination (ADAPT) programme was launched in Kalahandi-Bolangir-Koraput (KBK) region in 1988 during the visit of Mr. Rajiv Gandhi, the then Prime Minister of India. He had made special arrangements under this centrally aided scheme so as to facilitate the funds flow directly to KBK region. But the scheme was discontinued when Janata Dal Government led by V.P. Singh assumed the office. The explanation for the termination of the programme within one and half year of its launch was that the programme would not have been sustainable in the long-run, which seems to be inaccurate (Das, 1996). There were no such significant differences between this programme and other similar programmes which were in operation then. Moreover, the sustainability of these programmes is largely related to political commitment and peoples' participation which were found to be lacking in the study region.

The Drought Prone Area Programme (DPAP) was initiated in two districts of Odisha in 1970. It covered Bolangir district in 1982-83, nearly after 12 years. Though Bolangir was one of the most drought affected districts, such kind of diversion and delay in implementation of the programme in the district was believed to be due to political favoritism (Samal et al., 2003). The performances and leakages out of these programmes continued to be the major agenda during the election campaign. Political parties are interested in making allegations and counter allegations against each other and to take the credit of implementation of various public programmes and disbursement of funds without looking at periodic impact evaluation of these programmes at grass root level[11].

Besides vertical and horizontal political conflicts, the third kind of political negligence, which of course a paradoxical situation, that Odisha faced, was that even if the same government was in power both at the Centre and in the State, the sorrow of Odisha was not wiped out. During the severe drought of 2002, the ruling party at the Centre and in the State was the same (BJP led National Democratic Alliance). The State Government had submitted a memorandum to Government of India (GOI) in August 2002 seeking assistance of Rs 871.4 crore and 12.19 lakh tonnes of food grains for the drought mitigation works. The central team headed by the Joint Secretary to GOI visited the state twice to assess the extent of loss and crop damage. By the time of second visit, Odisha Government had sent additional memorandum for Rs 1676.8 crore and 10.7 lakh tonnes of food grain towards immediate requirement. But the Government of India disbursed a meagre sum of Rs 5.43 crore out of its National Calamity Relief Fund (NCRF) and the food grain assistance of 4.22 lakh tonnes in the first phase which were quite inadequate to meet the demand (GOI, 2003). The total funds and food grains available to the state in that year was Rs 422.9 crore and 7.64 lakh tonnes under all developmental programmes out of which 91 per cent of funds and 83 per cent of food grains were utilized. However, all these resources were not allocated for mitigating drought impacts alone. As presented in Table 1, the total amount allocated for drought mitigation in the state was Rs 10.8 crore and 4.22 lakh tonnes of food grains. The allocation for Bolangir district was Rs 4.43 crore out of which, about 80.5 per cent was meant for labour intensive works. Besides, 14.2 thousand tonnes of food grains was also allocated to the district for the labour intensive works for food for work component.

The fund-flow to the KBK region for drought proofing and other developmental works has been interrupted many times. It is claimed by the Centre that funds are not been utilized by the State Government, while the State Government alleges that the Central Government is not disbursing the funds in time. A major proportion of the allotment is disbursed towards the end of the financial year, which becomes difficult to spend (Indian Express, 2013). Furthermore, most of the KBK regions are Maoist affected. Many a times Maoists create hurdles in the developmental work. Sometimes it becomes difficult for the administration to find contractors for government work. All these hinder the drought proofing and development of this backward region. There is a need of proper coordination of various stakeholders to ensure the drought proofing and development works on the right track.

EFFECTIVENESS OF GOVERNMENT PROGRAMMES IN DROUGHT MANAGEMENT

Effective implementation of government programmes, improved credit and input delivery system, well-functioning public distribution system (PDS), good governance and village level institutions play a pivotal role in strengthening the resilience of rural households in withstanding drought impacts. An analysis of the extent of coverage and performance of the developmental programmes in the study area reveals many loopholes in their implementation. A few households had been covered under self-employment programmes implemented in the area. Table 2 shows that only 2.8 per cent of sample households were benefited by Swarnjayanti Gram Swarozgar Yojana (SGSY). The proportion of people benefited by TRYSEM was as low as 1.5 per cent of sample households. Only 0.22 per cent of sample households were benefited by the JRY programme. The proportion of people benefited by different programmes was about 12.1 per cent among sample households. While about 6.11 per cent households were benefited by the Indira Awas Yojana (IAY), the people benefited under Drought Prone Area Programme (DPAP), which was a major programme in the drought prone area, was very low (2.8%). Though the programme was undertaken with a watershed approach, there was no significant increase in irrigation through water harvesting in the region. The watershed programmes under different schemes including DPAP were also not very successful in increasing the cropping intensity or bringing about sustained changes in the cropping pattern. Though the programme was saturated in a study village (Samara), most of the sample households did not have any knowledge of the programme. The creation of durable assets and other long-term drought proofing activities were not taken up in true spirit and there was least participation of local people. Though the programme undertook vast array of activities, they were not properly integrated and did not serve the main objectives of the programme. Overall, the lack of effective implementation and poor peoples' participation in implementation of DPAP resulted in poor performance of the Programme in the region.

Notably, the self-help group (SHG) based activities have gathered momentum in the region. About 27.6 per cent households were found benefitted through SHGs. However, the proportion of households benefitted by NGOs was only 2.1 per cent during the reference year. As far as the quality of impacts is concerned, SHGs have also performed better in these areas with average rank value of 3.1 compared to that of NGOs (1.6) and government programmes (2.3).

The institutional sources of credit apparently failed in fulfilling the credit needs of vulnerable households. It may be seen from Table 3 that it has declined by 67.9 per cent for agricultural households and only by 1.2 per cent for non-agricultural households. Among agricultural farm households, the proportion of institutional credit availed by small and marginal farmers was reasonably low. Mainly large farmers and elite groups could avail more of institutional credit with subsidized interest rates, whereas the small and marginal farmers had to resort to private money lenders with exorbitant interest rates. The household level analysis reveals that the proportion of institutional credit increased to 81.9 per cent in the drought year from 76.9 per cent in the normal year for large farmers whereas the marginal farmer households could get only 19.9 per cent of its total credit from institutional sources in the drought year.

Moreover, many small and marginal farmers did not get the subsidized government loans due to diversions caused by the influence of political people (Swain, 2010). They not only suffered due to poor economic condition, but also were

Table 2. Coverage of developmental programmes in study villages

Sl. No.	Study Villages	% of Sample Households Benefited by:								(% of Sample Households)	
		DPAP	IRDP	TRYSEM	JRY	SGSY	IAY	EAS	All Programs	Benefited Through NGOs	Benefited Through SHGs
1	Samara	3.33	1.52	1.55	0	2.6	5.48	0.85	12.2	1.5	32.86
									(2.84)	(1.55)	(3.35)
2	Mundomahul	3.89	1.31	1.09	0	2.14	6.64	1.1	11.29	2.3	30.85
									(1.67)	(1.40)	(2.67)
3	Bijepur	1.24	2.1	1.96	0.7	4.06	6.8	1.87	15.43	2.5	19.17
									(2.17)	(1.67)	(3.17)
4	All	2.82	1.64	1.53	0.23	2.93	6.31	1.27	12.97	2.1	27.63
									(2.29)	(1.57)	(3.12)

Note: Figures in parentheses show the average score on a rating scale from 1 to 5 where 5 stands for 'excellent' impacts (highest) and 1 stands for 'very poor' impacts (lowest).

Source: Field survey data

Table 3. Access to various sources of credit (drought year vs. normal year)

Lending Agencies	All Farm Households			All Non-Farm Households			All Categories		
	NY	DY	% Change	NY	DY	% Change	NY	DY	% Change
Banks	7385.8	5824.3	-21.1	1294.3	844.7	-34.7	3324.8	2504.6	-24.7
	(53.3)	(51.5)		(17.0)	(10.6)		(29.8)	(23.6)	
Co-operatives	225.4	161.3	-28.4	192.5	450.2	133.9	352.2	611.6	73.7
	(1.6)	(1.4)		(2.5)	(5.7)		(3.2)	(5.8)	
Under Govt. programmes	356.5	126	-64.7	1081.6	1242.1	14.8	1455.4	1605.8	10.3
	(2.6)	(1.1)		(14.2)	(15.7)		(13.0)	(15.1)	
Village Organisations*	1139.9	1245.5	9.3	966	1247.3	29.1	1063.3	1232.2	15.9
	(8.2)	(11.0)		(12.7)	(15.7)		(9.5)	(11.6)	
Money lenders	847.3	852.5	0.6	1083.7	1350	24.6	1435.9	1502.9	4.7
	(6.1)	(7.5)		(14.2)	(17.0)		(12.8)	(14.2)	
Traders/Shop Keepers	931.6	2202	136.4	637.9	675.6	5.9	902	822.3	-8.8
	(6.7)	(19.5)		(8.4)	(8.5)		(8.1)	(7.8)	
Large Farmers	1334.5	2962.5	122	914.4	1120.1	22.5	1047.1	1128.1	7.7
	(9.6)	(26.2)		(12.0)	(14.1)		(9.4)	(10.6)	
Relatives	1628.7	1498.5	-8	1455.7	1003.2	-31.1	1594.3	1200.8	-24.7
	(11.8)	(13.2)		(19.1)	(12.6)		(14.3)	(11.3)	
Borrowing from Institutional Sources	7967.8	2559.1	-67.9	2568.4	2537	-1.2	5132.3	4722	-8
	(57.5)	(22.6)		(33.7)	(32.0)		(45.9)	(44.5)	
Borrowing from Private Sources	5881.9	8761	48.9	5057.6	5396.2	6.7	6042.6	5886.4	-2.6
	(42.5)	(77.4)		(66.3)	(68.0)		(54.1)	(55.5)	
Borrowing from all Sources	13849.7	11320.1	-18.3	7626	7933.2	4.0	11174.9	10608.4	-5.1
	(100.0)	(100.0)		(100.0)	(100.0)		(100.0)	(100.0)	

Notes: (1) DY stands for drought year and NY stands for normal year.

(2) *Village organizations included SHGs, Village Development Committee, Forest Protection Committee, Village Drought Action Committee and Youth Clubs.

(3) Figures in parentheses are the percentages of total.

Source: Field survey

humiliated due to not having political influence. As a result, they failed to avail the benefits of a large number of developmental programmes those were specifically meant for them. Higher strata of the society were able to siphon off the resources originally meant for the poorer section. The only alternative left for the landless and marginal farmers was to repeatedly visit the large farmers' or moneylenders' doorstep to get the linked loans at exorbitant interest rates accepting large-scale exploitation. Overall, the institutional credit did not help the farmers to the desirable extent to cope with the drought in the region.

The essential items like rice, kerosene and sugar were made available in required quantity in the sample villages through the targeted Public Distribution System (PDS). However, people could not purchase their full quota of subsidized food materials from the local dealers due to lack of purchasing power induced by widespread poverty (Swain, 2010). More importantly, they were unable to arrange money within the stipulated due date for purchasing the PDS items. It is worth mentioning that the proportion of households having purchased PDS rice increased marginally from 66.2 per cent in the normal year to 68.3 per cent in the drought year. However, some deserving landless and marginal farmer households (13.7%) were excluded from the benefits of targeted PDS due to discrepancy in preparation of the list of BPL households whereas some of the better off people were BPL card holders. Furthermore, some families managed to get multiple number of BPL cards also. Such kind of irregularity in allotment of BPL cards has weakened the effectiveness of PDS as a safety net to the poor households.

As far as the infrastructure provisions for withstanding the drought are concerned, irrigation is the foremost requirement in the area. The irrigation coverage in the district hovered around merely 23 per cent. The major sources of irrigation in the study region are micro level water sources like dug wells, tanks and cross bunds. The percentage of irrigated area under dug wells to gross irrigated area in the normal year and drought year was 35 per cent and 42 per cent respectively (Swain, 2006). It is worth mentioning that the major and medium irrigation systems did not contribute a single drop of irrigation water to the sample households. The shortage of water in the drought year has resulted in a frequent intra-village and inter-village conflicts. Since water for irrigation is very scarce, particularly in the drought year, the frequent conflicts among water users are obvious outcome. Again, the inter-village conflicts were found to be more in the study area compared to intra-village conflicts. This shows the lack of cohesion among the village level institutions in the study area. The frequent conflicts among farmers over sharing of water have resulted in loss of irrigation water. Moreover, the farmers in the area usually depend on lift irrigation but the water charges are high. The poor farmers find it difficult to pay the water charges to avail irrigation. On the other hand, the cost of lifting the water through pump sets has increased significantly. The power unavailability and low voltage have also been the major causes of concern for the farmers.

Out of three study villages, two (Samara and Mundomahul) were watershed villages and one (Bijepur) was non-watershed village. However, the proportion of irrigated lands was more in Bijepur compared to two other villages due to well-developed water harvesting structures, particularly cross bunds. Though a number of soil and water conservation measures have been undertaken under watersheds in the study villages[12], they are not well managed due to poor quality of works and lack of peoples' participation. However, in the non-watershed village (Bijepur), stronger village level organization with more educated population helped in better maintenance of the structures and better spread of awareness among the villagers.

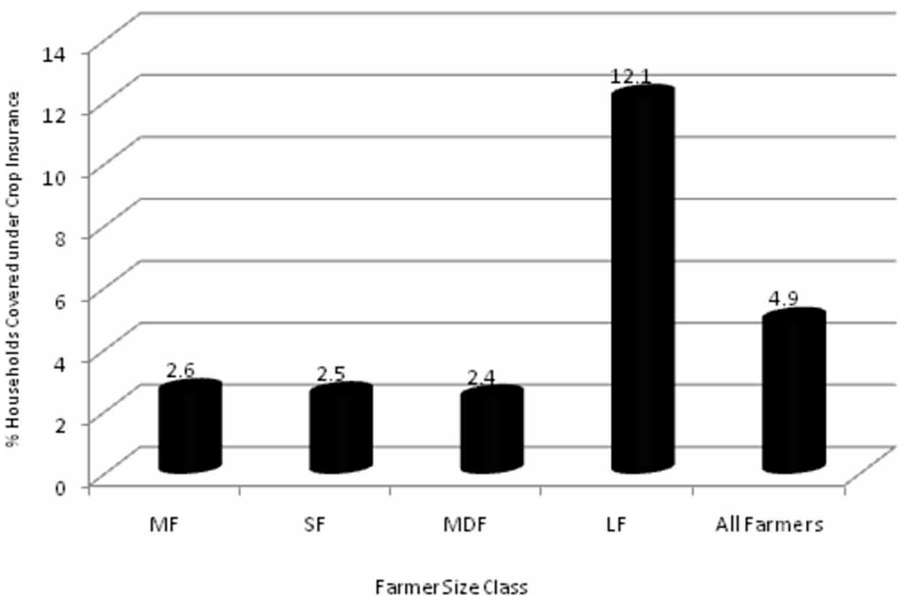
In spite of all the adaptation and mitigation measures taken up by the State Government and the farmers, if there is a crop failure, crop insurance is a mechanism to provide economic support to the farmers and stabilize their income. Crop insurance is considered as the one of the most effective institutional mechanisms to compensate the farmers for their losses due to events which are quite unpredictable and cannot be prevented. However, the percentage of net sown area covered under crop insurance in Bolangir district was very low (3.8%) (Table 4). Among the study blocks, the coverage was as low as 1.7 per cent in Titlagarh and 3.3 per cent and 4.2 per cent in Patnagarh and Saintala respectively. As per the household survey data (Figure 1), the large farmers (12%) insured their crops to a larger extent compared to other category of farmers. Overall, about 4.9 per cent sample farmers were insured under crop insurance scheme.

However, the sample farmers expressed their anguish over the procedure followed for declaration of crop loss in their locality. During a group

Table 4. Change in crop insurance coverage in drought year (2002) over normal year

Study Blocks and District	% Farmers Covered in 2002	% NSA Covered in 2002	2002 over 2001 (% Increase)			2002 over 2003 (% Increase)		
			Loanee	Non-Loanee	Total	Loanee	Non-Loanee	Total
Titlagarh	1.67	1.74	46.7	98.4	94.5	8.3	94.7	88.1
Patnagarh	3.34	2.79	44.1	100	93.6	21.8	95.7	87.2
Saintala	4.23	2.59	47.8	95.8	88.7	33.5	98.6	88.9
Bolangir district	3.80	3.81	46.6	99.5	91.9	26.2	94.3	84.5
Source: GIC of India, Bhubaneswar								

Figure 1. Crop insurance coverage



discussion with the farmers in a study village Samara, a large farmer said, "for the drought year 2002-03, only 16 per cent crop loss was declared. He had paid premium of Rs 120 per acre for 15 acres. Though the actual crop loss was about 50-74 per cent, the government declared considerably less crop loss so as to pay less. They picked good irrigated plots for crop cutting experiment and declared the entire region as less affected on that basis. On the other hand, the district was less affected by drought during 2001, and the actual crop loss was relatively less, but the crop loss declared was 48 per cent". Thus the discrepancy was observed in declaration of crop loss in different localities of the district. The lack of awareness about the scheme and the limited time period allowed for enrolling for crop insurance also resulted in large scale exclusion. Some farmers also expressed that the payment of claims against the crop loss reached them very late.

Besides government departments/agencies, there were many NGOs and community based organizations (CBOs) operating in the region and taking up various activities to make the region more climate resilient. Some of the NGOs associated with drought proofing and other developmental works in the area are Jangal Surakshya O Parichalana Forum, Aggragamee, Sahara, Praninka Pratisthan, Jana Kalyan, Prayas etc. As stated earlier (Table 2), the sample farmers were not benefited by these NGOs in real sense. On the other hand, working of CBOs and Self Help Groups (SHGs) is praiseworthy. Some of the CBOs in the study villages were Village Development Committee, Forest Protection Committee, Village Drought Action Committee, Youth Clubs and SHGs. These organizations judiciously managed their common pool resources such as available irrigation water, village ponds, community forests and grazing lands and resolved a number of inter-village and intra-village conflicts amicably, particularly related to water distribution. Women headed SHGs helped their households by generating additional income and participated in the activities of village level institutions. SHGs have undertaken handicraft activities using bamboo, paddy grain, cotton thread, *kaincha* etc., and they sell the products at local and regional market. Youth Clubs in the study villages have looked after overall developmental activities in the village including development of common property resources (CPRs), leasing-in village ponds for fishing and investing the profit for village development.

It is revealed through group discussion with the farmers that the community level mechanism to combat drought was stronger in earlier periods. For instance, about 30 years back, paddy collection group known as *Jagannath Dhana Fund* (a grain bank) was operating in the village Samara. The group was providing loan in terms of paddy, transacting 1 *khandi*[13] against 1.5 khandi, thereby making a profit of 0.5 *khandi* per *khandi* paddy invested. It was helping the poor farmers in the time of distress, as they were repaying after harvesting of their crops. The village development committee utilized the profit on developmental works including strengthening of village infrastructures. But such types of disciplined and well-managed organizations are now-a-days non-existent in the study villages. Such institutions gradually disappeared due to increased reliance on government run public distribution system.

CONCLUSION

The frequent occurrence of drought along with weak coping capacity of the people has resulted in perpetual backwardness of western Odisha. Huge flow of funds to the region under various special programmes such as Backward Regions Grant Fund, Biju KBK plan, Special Problem Fund, Integrated Action Plan and long-term developmental programmes through Western Odisha Development Council (WODC) have not helped much in strengthening the coping capacity to the desirable extent in the region. To ensure better targeting and governance, the government policies and programmes have been refined over the years and the institutional support system has been strengthened with the experiences of successive droughts. However, the institutional performance in allocating resources and implementing the developmental programmes are observed to be influenced by the nature of centre-state relationship and manipulation by pressure groups. A large number of developmental programmes have been implemented in the drought prone study region but the benefits of these programmes have reached very less proportion of rural households and these programmes have not been sustained due to lack of long-term vision, poor quality of program implementation and insufficient peoples' participation. There is a need for livelihood focused interventions with high priority to peoples' participation for their sustainability. There is an urgent need to make the system more efficient and transparent so that these programmes help in strengthening the coping capacity of rural households for effectively dealing with drought risk that seems to be rising in the region along with the intensification of climate change.

There are many areas where coping capacity can be strengthened with effective policy interventions. Increasing irrigation coverage has to be given due importance. There is huge scope for increasing irrigation in the district through developing micro level water resources. The traditional tanks (locally known as *Kata, Bandha, Chahala* etc.) have proved to be extremely useful not only in normal years but also in water scarce years. Small size water harvesting structures (WHSs) are advantageous over medium and large irrigation projects in Bolangir due to its uneven and hilly topography and other socioeconomic and biophysical factors. So instead of going for big dams which require massive investment and a long time for completion, efforts should be made to increase the irrigation coverage through WHSs such as dug wells, check dams, tanks and renovate the existing defunct WHSs. Though WHSs are quite feasible in the region[14], poor economic standards of majority of farmers, insufficient power availability, political negligence and weak institutional set up are the major hindrances for their sustainability. The financial constraints may be eased by encouraging community mobilization of resources, provision of performance based incentives and effective institutional development. Agricultural research and extension activities need to be strengthened through institutional support for better drought management.

The crop insurance coverage (which was only 3.8 per cent) needs to be increased for reducing the level of drought risk of farmer community. The lack of proper marketing facilities coupled with the problem of credit availability from institutional sources and shortage of power supply have forced many prospective farmers to avoid cultivating remunerative cash crops like sugarcane and cotton. Thus, much emphasis is required to be given on infrastructure development in the region. Infrastructure development is the first step for accelerating growth and livelihood promotion and diversification in the region.

There is a need for harmonious relationship between the Centre and State Government so as to facilitate effective implementation of development programmes in the region. Smooth flow of funds from Centre to the State, convergence of development programmes and the proper utilization of funds require proper coordination between the Centre and State Government and the strong political will of the State Government. The strong political will of the State Government may improve the governance, accountability and transparency in implementation of the programmes. There is a need to strengthen the local level organizations with more empowerment and better command for conflict resolutions.

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ENDNOTES

1 The major common strategies followed by the drought afflicted rural households for adjusting with drought in the region were borrowings from institutional sources and private lenders, reducing consumption, disposal of assets and livestock, increased dependence on CPRs, livelihood diversification, migration etc. As far as the cultivator households are concerned, they found to adopt some strategies like curtailing cost of cultivation, diversifying cropping pattern, crop insurance and creating/renovating WHSs etc (Swain, 2010).

2 The KBK region in western Odisha was earlier constituted by three districts namely, Kalahandi, Bolangir and Koraput which were divided into eight districts later on in 1992-93. The eight districts of KBK region are Kalahandi, Nuapara, Bolangir, Sonepur, Koraput, Rayagada, Nowrangpur and Malkanagiri. These districts in western Orissa are well known for prevalence of chronic poverty, widespread illiteracy, malnutrition and periodic out migration. The entire western Odisha districts (10 in number) lag behind their counterparts of coastal districts in core sectors. Looking at the degree of development/ backwardness of 10 Western Orissa districts, it can be said that out of 87 blocks only 5 blocks are developed, 25 are developing, another 25 are backward and 32 blocks are very backward, whereas in coastal districts 70 blocks are developed, 50 blocks are very backward out of total 227 blocks (GOO, 2013).

3 The degree of drought vulnerability in the blocks was estimated according to the value of Composite Drought Vulnerability Index (CDVI) constructed on the basis of ranks or weights attached to nineteen key drought vulnerability factors out of which six were biophysical factors (i.e., drought probability, intensity, long-term rainfall variability, water holding capacity of soil, land slope, and ground water table) and thirteen were socio-economic factors (poverty, education, irrigation, major crop production, land use pattern and some important institutional factors).

4 The twelve major livelihood groups were: large farmer (average size of operational area of more than 4 hectares), medium farmer (2-4 hectares), small farmer (1-2 hectares), marginal farmer (up to 1 hectare), agricultural labourer, non-agricultural labourer, forest resource dependant, rural artisan, businessman, service holder, livestock rearer, and others covering fishing community, stone merchants, and tailors.

5 The main objective of the JRY was additional gainful employment for the unemployed and under-employed persons in rural areas. The other objective was the creation of sustained employment by strengthening rural economic infrastructure and assets in favour of rural poor for their direct and continuing benefits. An evaluation study of this scheme by planning commission (GOI, 1991) revealed that

the scheme helped in employment generation for SCs, STs and weaker sections, but the quality of maintenance of assets in most of the cases was found to be either average or poor.

6 IRDP was a rural development program of the Government of India launched in financial year 1978 and extended throughout India by 1980. It was a self-employment programme intended to raise the income-generation capacity of target groups among the poor. The target group consisted largely of small and marginal farmers, agricultural labourers and rural artisans living below the poverty line.

7 TRYSEM was the largest scheme launched by the Government of India to address the problem of training the rural youth for employment. Training was imparted through formal institutions, including industrial and servicing units, commercial and business establishments and through master craftsmen. Rural youth aged 18-35 were eligible. The programme was expected to cover a minimum of 50 percent of the youth from the scheduled caste and tribe communities and a minimum of 3 percent from the ranks of the physically handicapped.

8 SGSY was launched in 1999 to focus on promoting self-employment among rural poor. It was remodeled to form National Rural Livelihood Mission (NRLM) in 2011 with a budget of $ 5.1 billion and is one of the flagship programmes of Ministry of Rural Development, which is being supported by World Bank. This is one of the world's largest initiatives to improve the livelihood of poor.

9 A very senior IAS officer was posted as the Chief Administrator, Special Area Development (KBK) Project. He was responsible for effective monitoring and supervising the implementation of various programmes. His office was also vested with enhanced financial power. The Revenue Divisional Commissioners of Southern and Northern Divisions were made Deputy Chief Administrators with well-defined financial powers. The central government was very much pleased with such institutional arrangement for speedy and transparent implementation of the programme.

10 At present, WODC covers 10 western Odisha districts (Bargarh, Bolangir, Deogarh, Jharsuguda, Kalahandi, Nuapada, Sambalpur, Sonepur and Sundargarh and Boudh) and Athmalik block of Angul district.

11 One example of allegations and counter allegations on the implementation of the developmental programmes for drought mitigation in the study region may be cited here. A congressman said, ‘‘BJP is claiming that Revised Long Term Action Plan (RLTAP) for KBK was started by NDA government. In fact, it was envisioned by Rajiv Gandhi and was started during Congress government with Narshimha Rao as the prime minister. The prime minister in his address to congress delegation mentioned that NDA Government, in 6 years of its rule, disbursed Rs 700 crore for development of KBK region, while Congress led UPA Government during the first 2 years of its tenure disbursed Rs 500 crore and another Rs 1500 crore is in the pipeline”. So they asserted that the state government should stop false propaganda and take the people of Odisha for a ride.

12 Some soil and water conservation measures undertaken as part of watershed programme on arable lands were establishment of contour vegetative hedges and construction of gully control structures with vegetative measures. The measures carried out on non-arable lands were planting by over seeding of grasses and legumes as per the suitability of the lands, afforestation and silvi-pastural intervention and construction of check dams at upper reaches and loose

boulder check dams and earthen structures at middle reaches of the watershed.

13 1 Khandi is equivalent to 20 kg.

14 The availability of groundwater resources is also conducive for development of WHSs in the region. There is not a single over-exploited zone in the district. The groundwater development is 16.77% and the average depth of groundwater level varies from 0.78 mbgl (metre below ground level) to 6.85 mbgl during post monsoon period and from 1.33 mbgl to 8.85 mbgl during pre-monsoon period (CGWB 2007).

Section 4
Water

Chapter 10
Impact of Climate Change on Groundwater Resources

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ABSTRACT

Climate change poses uncertainties to the supply and management of water resources. While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels, and saline intrusion in coastal aquifers due to sea level rise and resource reduction. This chapter presents the likely impact of climate change on groundwater resources and methodology to assess the impact of climate change on groundwater resources.

INTRODUCTION

Water is indispensable for life, but its availability at a sustainable quality and quantity is threatened by many factors, of which climate plays a leading role. The Intergovernmental Panel on Climate Change (IPCC) defines climate as "the average weather in terms of the mean and its variability over a certain time-span and a certain area" and a statistically significant variation of the mean state of the climate or of its variability lasting for decades or longer, is referred to as climate change.

Evidence is mounting that we are in a period of climate change brought about by increasing atmospheric concentrations of greenhouse gases. Atmospheric carbon dioxide levels have continually increased since the 1950s. The continuation of this phenomenon may significantly alter global and local climate characteristics, including temperature and precipitation. The Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature has increased 0.6 $\pm$ 0.2 ^{o}C since 1861, and predicts an increase of 2 to 4 ^{o}C over the next 100 years. Global sea levels have risen between 10 and 25 cm since the late 19th century. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation. Predictions include higher incidences of severe weather

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events, a higher likelihood of flooding, and more droughts. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India.

Climate change can have profound effects on the hydrologic cycle through precipitation, evapotranspiration, and soil moisture with increasing temperatures. The hydrologic cycle will be intensified with more evaporation and more precipitation. However, the extra precipitation will be unequally distributed around the globe. Some parts of the world may see significant reductions in precipitation or major alterations in the timing of wet and dry seasons. Information on the local or regional impacts of climate change on hydrological processes and water resources is becoming more important.

Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. The direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Therefore, quantifying the impact of climate change on groundwater resources requires not only reliable forecasting of changes in the major climatic variables, but also accurate estimation of groundwater recharge.

The effects of global warming and climatic change require multi-disciplinary research, especially when considering hydrology and global water resources. This chapter discusses the likely impact of climate change on soil moisture, groundwater recharge, coastal aquifers; present status of research studies; and methodology to assess the impact of climate change on groundwater resources.

BACKGROUND

Changes in regional temperature and precipitation have important implications for all aspects of the hydrologic cycle. Variations in these parameters determine the amount of water that reaches the surface, evaporates or transpires back to the atmosphere, becomes stored as snow or ice, infiltrates into the groundwater system, runs off the land, and ultimately becomes base flow to streams and rivers.

Temperature increases affect the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, timings and intensity rates, and indirectly impact the flux and storage of water in surface and subsurface reservoirs (i.e., lakes, soil moisture, groundwater). In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration, potable water shortage, etc.

Many rivers and streams that are fed by glacier runoff could be significantly impacted as a result of climate change. As glacier retreat accelerates, increased summer runoff could occur. However, when the glaciers have largely melted, the late summer and fall glacial input into streams and rivers may be lost, resulting in a significant reduction in flow in some cases.

Hydrological impact assessments of watersheds (and aquifers) require information on changes in evapotranspiration because it is a key component of the water balance. However, climate-change scenarios tend to be expressed in terms of changes in temperature and precipitation. Consequently, the effects of global warming on potential evaporation (or more inclusively, evapotranspiration) are not simple to estimate. Many global scenarios suggest an increase in potential evaporation, but these factors may be outweighed locally or regionally by other factors reducing evaporation. Various models may be used to calculate potential evaporation using data on net radiation, temperature, humidity, and wind speed, and sometimes plant physiological properties. The estimated effect of a change in climate on potential evaporation depends on the characteristics of the site.

Water resource management plans increasingly need to incorporate the effects of global climate change in order to accurately predict future supplies. Numerous studies have documented the sensitivity of streamflow to climatic changes for watersheds all over the world. Most of these studies involve watershed scale hydrologic models, of which validation remains a fundamental challenge. Moreover, outputs from general circulation models (GCM) can be rather uncertain and downscaling their predictions for local hydrologic use can produce inconsistent results. Therefore, the sensitivity of streamflow to climate changes is perhaps best understood by analyzing the historical records.

Building empirical models to link climate and regional hydrological regimes has a long history. In recent years, many researchers have used empirical rainfall–runoff model to study the impacts of climatic change on hydrology. However, applications of these empirical relationships to climate or basin conditions different from those used in the original development of these functions are questionable.

IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES

Although the most noticeable impacts of climate change could be fluctuations in surface water levels and quality, the greatest concern of water managers and government is the potential decrease and quality of groundwater supplies, as it is the main available potable water supply source for human consumption and irrigation of agriculture produce worldwide. Because groundwater aquifers are recharged mainly by precipitation or through interaction with surface water bodies, the direct influence of climate change on precipitation and surface water ultimately affects groundwater systems.

It is increasingly recognized that groundwater cannot be considered in isolation from the landscape above, the society with which it ‘interacts’, or from the regional hydrological cycle, but needs to be managed holistically. In understanding the likely consequences of possible future (climate and non-climate) changes on groundwater systems and the regional hydrological cycle, an important (but not exclusive) component to understand is the influence that these factors exert on recharge and runoff.

It is important to consider the potential impacts of climate change on groundwater systems. As part of the hydrologic cycle, it can be anticipated that groundwater systems will be affected by changes in recharge (which encompasses changes in precipitation and evapotranspiration), potentially by changes in the nature of the interactions between the groundwater and surface water systems, and changes in use related to irrigation.

Soil Moisture

The amount of water stored in the soil is fundamentally important to agriculture and has an influence on the rate of actual evaporation, groundwater recharge, and generation of runoff. Soil moisture contents are directly simulated by global climate models, albeit over a very coarse spatial resolution, and outputs from these models give an indication of possible directions of change.

The local effects of climate change on soil moisture, however, will vary not only with the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate change. Climate change also may affect soil characteristics, perhaps through changes in waterlogging or cracking, which in turn may affect soil moisture storage properties. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing.

Groundwater Recharge and Resources

Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change.

Aquifers generally are replenished by effective rainfall, rivers, and lakes. This water may reach the aquifer rapidly, through macro-pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlying the aquifer. A change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. Increased winter rainfall, as projected under most scenarios for mid-latitudes, generally is likely to result in increased groundwater recharge. However, higher evaporation may mean that soil deficits persist for longer and commence earlier, offsetting an increase in total effective rainfall. Various types of aquifer will be recharged differently. The main types are unconfined and confined aquifers. An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of overlying rocks and soils.

Macro-pore and fissure recharge is most common in porous and aggregated forest soils and less common in poorly structured soils. It also occurs where the underlying geology is highly fractured or is characterized by numerous sinkholes. Such recharge can be very important in some semi-arid areas. In principle, "rapid" recharge can occur whenever it rains, so where recharge is dominated by this process it will be affected more by changes in rainfall amount than by the seasonal cycle of soil moisture variability.

Shallow unconfined aquifers along floodplains, which are most common in semi-arid and arid environments, are recharged by seasonal streamflows and can be depleted directly by evaporation. Changes in recharge therefore will be determined by changes in the duration of flow of these streams, which may locally increase or decrease, and the permeability of the overlying beds, but increased evaporative demands would tend to lead to lower groundwater storage. The thick layer of sands substantially reduces the impact of evaporation.

It will be noted from the foregoing that unconfined aquifers are sensitive to local climate change, abstraction, and seawater intrusion. However, quantification of recharge is complicated by the characteristics of the aquifers themselves as well as overlying rocks and soils. A confined aquifer, on the other hand, is characterized by an overlying bed that is impermeable, and local rainfall does not influence the aquifer. It is normally recharged from lakes, rivers, and rainfall that may occur at distances ranging from a few kilometers to thousands of kilometers.

Aside from the influence of climate, recharge to aquifers is very much dependent on the characteristics of the aquifer media and the properties of the overlying soils. Several approaches can be used to estimate recharge based on surface water, unsaturated zone and groundwater data. Among these approaches, numerical modelling is the only tool that can predict recharge. Modelling is also extremely useful for identifying the relative importance of different controls on recharge, provided that the model realistically accounts for all the processes involved. However, the accuracy of recharge estimates depends largely on the availability of high quality hydrogeologic and climatic data. Determining the potential impact of climate change on groundwater resources, in particular, is difficult due to the complexity of the recharge process, and the variation of recharge within and between different climatic zones.

Attempts have been made to calculate the rate of recharge by using carbon-14 isotopes and other modeling techniques. This has been possible for aquifers that are recharged from short distances and after short durations. However, recharge that takes place from long distances and after decades or centuries has been problematic to calculate with accuracy, making estimation of the impacts of climate change difficult. The medium through which recharge takes place often is poorly known and very heterogeneous, again challenging recharge modeling. In general, there is a need to intensify research on modeling techniques, aquifer characteristics, recharge rates, and seawater intrusion, as well as monitoring of groundwater abstractions. This research will provide a sound basis for assessment of the impacts of climate change and sea-level rise on recharge and groundwater resources.

Coastal Aquifers

When considering water resources in coastal zones, coastal aquifers are important sources of freshwater. However, salinity intrusion can be a major problem in these zones. Salinity intrusion refers to replacement of freshwater in coastal aquifers by saltwater. It leads to a reduction of available fresh groundwater resources. Changes in climatic variables can significantly alter groundwater recharge rates for major aquifer systems and thus affect the availability of fresh groundwater. Salinization of coastal aquifers is a function of the reduction of groundwater recharge and results in a reduction of fresh groundwater resources.

Sea-level rise will cause saline intrusion into coastal aquifers, with the amount of intrusion depending on local groundwater gradients. Shallow coastal aquifers are at greatest risk. Groundwater in low-lying islands therefore is very sensitive to change. A reduction in precipitation coupled with sea-level rise would not only cause a diminution of the harvestable volume of water; it also would reduce the size of the narrow freshwater lense. For many small island states, such as some Caribbean islands, seawater intrusion into freshwater aquifers has been observed as a result of overpumping of aquifers. Any sea-level rise would worsen the situation.

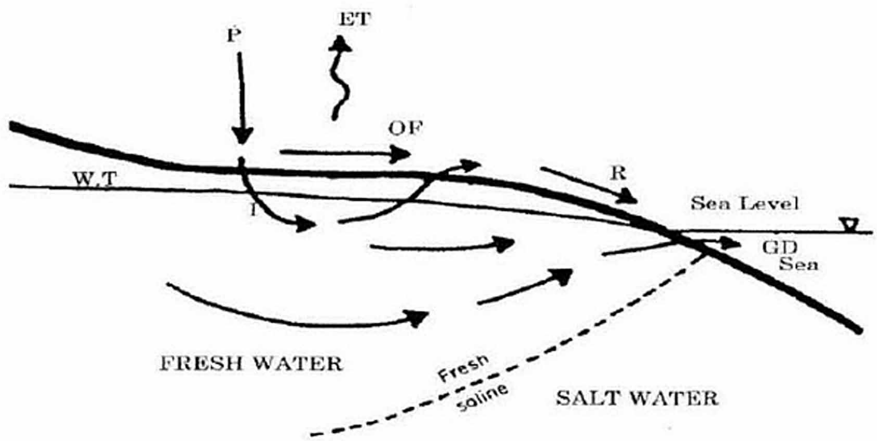
A link between rising sea level and changes in the water balance is suggested by a general description of the hydraulics of groundwater discharge at the coast. Fresh groundwater rides up over denser, salt water in the aquifer on its way to the sea (Figure 1), and groundwater discharge is focused into a narrow zone that overlaps with the intertidal zone. The width of the zone of groundwater discharge measured perpendicular to the coast, is directly proportional to the discharge rate. The shape of the water table and the depth to the freshwater/saline interface are controlled by the difference in density between freshwater and salt water, the rate of freshwater discharge and the hydraulic properties of the aquifer. The elevation of the water table is controlled by mean sea level through hydrostatic equilibrium at the shore.

To assess the impacts of potential climate change on fresh groundwater resources, we should focus on changes in groundwater recharge and sea level rise on the loss of fresh groundwater resources in water resources stressed coastal aquifers.

Status of Research Studies

The increase of concentration of carbon dioxide and other greenhouse gases in the atmosphere will certainly affect hydrological regimes. Global warming is thus expected to have major implications on water resources management. The observation of long-term trends in climate for many regions of the world has led to considerable research on the impact of greenhouse gases on climate. To this end, several general circulation models (GCMs) have been used to simulate the type of climate that might exist if global concen-

Figure 1. Conceptual model of the water balance in a coastal watershed



trations of carbon dioxide (greenhouse gas) were twice their pre-industrial levels. Recent GCM estimates of the projected rise in long-term global average annual surface temperature are between 1 and 4.5 °C under simulated doubled concentrations of CO_2. On the subcontinent scale, there remains considerable uncertainty in the model results and it is not possible to know with confidence the fine details of how the climate will change regionally (Taylor 1997). Consequently, it is customary to use observational data as a baseline and adjust these by the GCM scenarios (Taylor 1997). Because precipitation patterns are significantly influenced by changes in the global-circulation patterns induced by climate change, regional projections for changes in precipitation under doubled CO_2 scenarios remain very uncertain.

There have been many studies relating the effect of climate changes on surface water bodies. However, very little research exists on the potential effects of climate change on groundwater, although groundwater is the major source of drinking water across much of the world and plays a vital role in maintaining the ecological value of an area. Available studies show that groundwater recharge and discharge conditions are reflection of the precipitation regime, climatic variables, landscape characteristics and human impacts such as agricultural drainage and flow regulation. Hence, predicting the behavior of recharge and discharge conditions under future climatic and other changes is of great importance for integrated water management.

Studies which consider the indirect effects derived from climate-change-induced alterations in soil, land cover, salt-water intrusion due to rising sea levels and changes in water demand are less common. These studies represent a move away from impact studies (which may be considered to be vertically integrated, in which climate change acts upon an environmental compartment) towards horizontally integrated studies in which environmental compartments interact with each other. However, they remain an incomplete assessment of the pressures facing groundwater resources associated with the direct and indirect effects of future climate and socio-economic change.

Previous studies have typically coupled climate change scenarios with hydrological models, and have generally investigated the impact of climate change on water resources in different areas. The scientific understanding of an aquifer's response to climate change has been studied in several locations within the past decade. These studies link atmospheric models to unsaturated soil models, which, in some cases, were further linked into a groundwater model. The groundwater models used were calibrated to current groundwater conditions and stressed under different predicted climate change scenarios. Some of the recent studies on impact of climate change on groundwater resources have been discussed below.

Kirshen (2002) used the groundwater model MODFLOW to study the impact of global warming on a highly permeable aquifer in the northeastern United States. Groundwater recharge was estimated using a separate model based on precipitation and potential evapotranspiration. Both hypothetical and GCM-predicted changes to the input parameters were used, resulting in higher, no different, and significantly lower recharge rates and groundwater elevations, depending on the climate scenario used.

Croley and Luukkonen (2003) investigated the impact of climate change on groundwater levels in Lansing, Michigan. The groundwater recharge rates were based on an empirical streamflow model which was calibrated using the results from two GCMs. The results of the study indicated that the simulated steady-state groundwater levels were generally predicted to increase or decrease due to climate change, depending on the GCM used.

Eckhardt and Ulbrich (2003) investigated the impact of climate change on groundwater recharge and streamflow in a small catchment in Germany. The input parameters in their hydrologic model were adjusted based on simulations from five different GCMs. The results of the study indicated that more precipitation will fall as rain in winter due to increased temperatures, resulting in higher recharge and streamflow in January and February. They also found that the increase in recharge from the snowmelt in March disappears, while recharge and streamflow were shown to be potentially reduced in the summer months.

Loaiciga (2003) studied a karst aquifer in south-central Texas and considered the impact of climate change not only on streambed recharge, but also on pumping rates (i.e. groundwater use). The impact of climate change on the streambed recharge was estimated using runoff scaling factors based on the ratio of historical and future streamflows predicted from linked general and regional climate models. The study concluded that the rise in groundwater use associated with predicted population growth would pose a higher threat to the aquifer than climate change.

Allen et al. (2004) used the Grand Forks aquifer, located in south-central British Columbia, Canada as a case study area for modeling the sensitivity of an aquifer to changes in recharge and river stage consistent with projected climate-change scenarios for the region. Results suggested that variations in recharge to the aquifer under the different climate-change scenarios, modeled under steady-state conditions, have a much smaller impact on the groundwater system than changes in river-stage elevation of the Kettle and Granby Rivers, which flow through the valley. All simulations showed relatively small changes in the overall configuration of the water table and general direction of groundwater flow. High-recharge and low-recharge simulations resulted in approximately a +0.05 m increase and a –0.025 m decrease, respectively, in water table elevations throughout the aquifer. Simulated changes in river-stage elevation, to reflect higher-than-peak flow levels (by 20 and 50%), resulted in average changes in the water-table elevation of 2.72 and 3.45 m, respectively. Simulated changes in river-stage elevation, to reflect lower-than-base flow levels (by 20 and 50%), resulted in average changes in the water-table elevation of -0.48 and -2.10 m, respectively. Current observed water table elevations in the valley are consistent with an average river-stage elevation (between current base flow and peak-flow stages).

Brouyere et al. (2004) developed an integrated hydrological model (MOHISE) in order to study the impact of climate change on the hydrological cycle in representative water basins in Belgium. This model considers most hydrological processes in a physically consistent way, more particularly groundwater flows which are modelled using a spatially distributed, finite-element approach. Thanks to this accurate numerical tool, after detailed calibration and validation, quantitative interpretations can be drawn from the groundwater model results. Considering IPCC climate change scenarios, the integrated approach was applied to evaluate the impact of climate change on the water cycle in the Geer basin in Belgium. The groundwater model is described in detail and results are discussed in terms of climate change impact on the evolution of groundwater levels and groundwater reserves. From the modelling application on the Geer basin, it appears that, on a pluri-annual basis, most tested scenarios predict a decrease in groundwater levels and reserves in relation to variations in climatic conditions. However, for this aquifer, the tested scenarios show no enhancement of the seasonal changes in groundwater levels.

Holman (2006) described an integrated approach to assess the regional impacts of climate and socio-economic change on groundwater recharge from East Anglia, UK. Many factors affect future groundwater recharge including changed precipitation and temperature regimes, coastal flooding, urbanization, woodland establishment, and changes in cropping and rotations. Important sources of uncertainty and shortcomings in recharge estimation were discussed in the light of the results. The uncertainty in, and importance of, socio-economic scenarios in exploring the consequences of unknown future changes were highlighted. Changes to soil properties are occurring over a range of time scales, such that the soils of the future may not have the same infiltration properties as existing soils. The potential implications involved in assuming unchanging soil properties were described.

Mall et al. (2006) examined the potential for sustainable development of surface water and groundwater resources within the constraints imposed by climate change and future research needs in India. In recent times, several studies around the globe show that climatic change is likely to impact significantly upon freshwater resources availability. In India, demand for water has already increased manifold over the years due to urbanization, agriculture expansion, increasing population, rapid industrialization and economic development. At present, changes in cropping pattern and land-use pattern, over-exploitation of water storage and changes in irrigation and drainage are modifying the hydrological cycle in many climate regions and river basins of India. An assessment of the availability of water resources in the context of future national requirements and expected impacts of climate change and its variability is critical for relevant national and regional long-term development strategies and sustainable development.

He concluded that the Indian region is highly sensitive to climate change. The elements/sectors currently at risk are likely to be highly vulnerable to climate change and variability. It is urgently required to intensify in-depth research work with the following objectives:

- Analyse recent experiences in climate variability and extreme events, and their impacts on regional water resources and groundwater availability.
- Study on changing patterns of rainfall, i.e. spatial and temporal variation and its impact on run-off and aquifer recharge pattern.
- Study sea-level rise due to increased run-off as projected due to glacial recession and increased rainfall.
- Sea-water intrusions into costal aquifers.
- Determine vulnerability of regional water resources to climate change and identify key risks and prioritize adaptation responses.
- Evaluate the efficacy of various adaptation strategies or coping mechanisms that may reduce vulnerability of the regional water resources.

It has been the endeavour of this study to summarize some important vulnerability issues associated with the present and potential future hydrological responses due to climate change and highlight those areas where further research is required. The National Environment Policy (2004) also advocated that anthropogenic climate changes have severe adverse impacts on India's precipitation patterns, ecosystems, agricultural potential, forests, water resources, coastal and marine resources. Large-scale planning would be clearly required for adaptation measures for climate change impacts, if catastrophic human misery is to be avoided.

Ranjan et al. (2006) evaluated the impacts of climate change on fresh groundwater resources specifically salinity intrusion in water resources stressed coastal aquifers. Their assessment used the Hadley Centre climate model, HadCM3 with high and low emission scenarios (SRES A2 and B2) for years 2000–2099. In both scenarios, the annual fresh groundwater resources losses indicated an increasing long-term trend in all stressed areas, except in the northern Africa/Sahara region. They also found that precipitation and temperature individually did not show good correlations with fresh groundwater loss. However, the relationship between the aridity index and fresh groundwater loss exhibited a strong negative correlation. They also discussed the impacts of loss of fresh groundwater resources on socio-economic activities, mainly population growth and per capita fresh groundwater resources.

Scibek and Allen (2006) developed a methodology for linking climate models and groundwater models to investigate future impacts of climate change on groundwater resources. An unconfined aquifer, situated near Grand Forks in south central British Columbia, Canada, was used to test the methodology. Climate change scenarios from the Canadian Global Coupled Model 1 (CGCM1) model runs were downscaled to local conditions using Statistical Downscaling Model (SDSM), and the change factors were extracted and applied in LARS-WG stochastic weather generator and then input to the recharge model. The recharge model simulated the direct recharge to the aquifer from infiltration of precipitation and consisted of spatially distributed recharge zones, represented in the Hydrologic Evaluation of Landfill Performance (HELP) hydrologic model linked to a geographic information system (GIS). A three-dimensional transient groundwater flow model, implemented in MODFLOW, was then used to simulate four climate scenarios in 1-year runs (1961–1999 present, 2010–2039, 2040–2069, and 2070-2099) and compare groundwater levels to present. The effect of spatial distribution of recharge on groundwater levels, compared to that of a single uniform recharge zone, is much larger than that of temporal variation in recharge, compared to a mean annual recharge representation. The predicted future climate for the Grand Forks area from the downscaled CGCM1 model will result in more recharge to the unconfined aquifer from spring to the summer season. However, the overall effect of recharge on the water balance is small because of dominant river-aquifer interactions and river water recharge.

Hsu et al. (2007) adopted a numerical modeling approach to investigate the response of the groundwater system to climate variability to effectively manage the groundwater resources of the Pingtung Plain. The Pingtung Plain is one of the most important groundwater-resource areas in southwestern Taiwan. The overexploitation of groundwater in the last two decades has led to serious deterioration in the quantity and quality of groundwater resources in this area. Furthermore, the manifestation of climate change tends to induce the instability of surface-water resources and strengthen the importance of the groundwater resources. Southwestern Taiwan in particular shows decreasing tendencies in both the annual amount of precipitation and annual precipitation days. A hydrogeological model was constructed based on the information from geology, hydrogeology, and geochemistry. Applying the linear regression model of precipitation to the next two decades, the modeling result shows that the lowering water level in the proximal fan raises an alarm regarding the decrease of available groundwater in the stress of climate change, and the enlargement of the low-groundwater-level area on the coast signals the deterioration of water quantity and quality in the future. Suitable strategies for water-resource management in response to hydrological impacts of future climatic change are imperative.

Jyrkama and Sykes (2007) presented a physically based methodology that can be used to characterize both the temporal and spatial effect of climate change on groundwater recharge. The method, based on the hydrologic model HELP3, can be used to estimate potential groundwater recharge at the regional scale with high spatial and temporal resolution. In this study, the method is used to simulate the past conditions, with 40 years of actual weather data, and future changes in the hydrologic cycle of the Grand River watershed. The impact of climate change is modelled by perturbing the model input parameters using predicted changes in the regions climate. The results of the study indicate that the overall rate of groundwater recharge is predicted to increase as a result of climate change. The higher intensity and frequency of precipitation will also contribute significantly to surface runoff, while global warming may result in increased evapotranspiration rates. Warmer winter temperatures will reduce the extent of ground frost and shift the spring melt from spring toward winter, allowing more water to infiltrate into the ground. While many previous climate change impact studies have focused on the temporal changes in groundwater recharge, results of this study suggest that the impacts can also have high spatial variability.

Toews (2007) modeled the impacts of future predicted climate change on groundwater recharge resources for the arid to semi-arid south Okanagan region, British Columbia. The hydrostratigraphy of the region consists of Pleistocene-aged glaciolacustrine silt overlain by glaciofluvial sand and gravel. Spatial recharge was modelled using available soil and climate data with the HELP 3.80D hydrology model. Climate change effects on recharge were investigated using stochastically-generated climate from three GCMs. Recharge is estimated to be ~45 mm/year, with minor increases expected with climate change. However, growing season and crop water demands will increase, posing additional stresses on water use in the region. A transient MODFLOW groundwater model simulates increases of water table in future time periods, which is largely driven by irrigation application increases. Spatial recharge was also used in a groundwater model to define capture zones around eight municipal water wells. These capture zones will be used for community planning.

Woldeamlak et al. (2007) modeled the effects of climate change on the groundwater systems in the Grote-Nete catchment, Belgium, covering an area of 525 km_2, using wet (greenhouse), cold or NATCC (North Atlantic Thermohaline Circulation Change) and dry climate scenarios. Low, central and high estimates of temperature changes were adopted for wet scenarios. Seasonal and annual water balance components including groundwater recharge were simulated using the WetSpass model, while mean annual groundwater elevations and discharge were simulated with a steady-state MODFLOW groundwater model. WetSpass results for the wet scenarios showed that wet winters and drier summers are expected relative to the present situation. MODFLOW results for wet high scenario showed groundwater levels increase by as much as 79 cm, which could affect the distribution and species richness of meadows. Results obtained for cold scenarios depict drier winters and wetter summers relative to the present. The dry scenarios predict dry conditions for the whole year. There is no recharge during the summer, which is mainly attributed to high evapotranspiration rates by forests and low precipitation. Average annual groundwater levels drop by 0.5 m, with maximum of 3.1 m on the eastern part of the Campine Plateau. This could endanger aquatic ecosystem, shrubs, and crop production.

Carneiro et al. (2008) applied a density dependent numerical flow model (FEMWATER) to study the climate change impact in an unconfined shallow aquifer in the Mediterranean coast of Morocco. The stresses imposed to the model were derived from the IPCC emission scenarios and included recharge variations, rising sea level and advancing seashore. The simulations show that there will be a significant decline in the renewable freshwater resources and that salinity increases can be quite large but are limited to a restricted area.

Dragoni and Sukhija (2008) analysed the main methods for studying the relationships between climate change and groundwater, and presented the main areas in which hydrogeological research should focus in order to mitigate the likely impacts. There is a general consensus that climate change is an ongoing phenomenon. This will inevitably bring about numerous environmental problems, including alterations to the hydrological cycle, which is already heavily influenced by anthropogenic activity. The available climate scenarios indicate areas where rainfall may increase or diminish, but the final outcome with respect to man and environment will, generally, be detrimental. Groundwater will be vital to alleviate some of the worst drought situations.

Herrera-Pantoja and Hiscock (2008) outlined a methodology to quantify the effects of climate change on potential groundwater recharge (or hydrological excess water) for three locations in the north and south of Great Britain. Using results from a stochastic weather generator, actual evapotranspiration and potential groundwater recharge time-series for the historic baseline 1961-1990 and for a future 'high' greenhouse gas emissions scenario for the 2020s, 2050s and 2080s time periods were simulated for Coltishall in East Anglia, Gatwick in southeast England and Paisley in west Scotland. Under the 'high' gas emissions scenario, results showed a decrease of 20% in potential groundwater recharge for Coltishall, 40% for Gatwick and 7% for Paisley by the end of this century. The persistence of dry periods is shown to increase for the three sites during the 2050s and 2080s. Gatwick presents the driest conditions, Coltishall the largest variability of wet and dry periods and Paisley little variability. For Paisley, the main effect of climate change is evident during the dry season (April-September), when the potential amount of hydrological excess water decreases by 88% during the 2080s. Overall, it is concluded that future climate may present a decrease in potential groundwater recharge that will increase stress on local and regional groundwater resources that are already under ecosystem and water supply pressures.

Franssen (2009) indicated the limitations of the studies that address the impact of climate change on groundwater resources and suggested an improved approach. A general review, both from a groundwater hydrological and a climatological viewpoint, is given, oriented on the impact of climate change on groundwater resources. The impact of climate change on groundwater resources is not the subject of many studies in the scientific literature. Only rarely sophisticated downscaling techniques are applied to downscale estimated global circulation model (GCM) future precipitation series for a point or region of interest. Often it is not taken into account that different climate models calculate considerably different precipitation amounts (conceptual uncertainty). The joint downscaling of the meteorological variables that govern potential evapotranspiration (ET) is never done in the context of a study that assessed the impact of climate change on groundwater resources. It is desirable that actual ET is calculated in (groundwater) hydrological models on a physical basis, i.e. by coupling the energy and water balance at the Earth's surface.

Holman et al. (2009) indicated that groundwater resource estimates require the calculation of recharge using a daily time step. Within climate-change impact studies, this inevitably necessitates temporal downscaling of global or regional climate model outputs. This paper compares future estimates of potential groundwater recharge calculated using a daily soil-water balance model and climate-change weather time series derived using change factor (deterministic) and weather generator (stochastic) methods for Coltishall, UK. The uncertainty in the results for a given climate-change scenario arising from the choice of downscaling method is greater than the uncertainty due to the emissions scenario within a 30-year time slice. Robust estimates of the impact of climate change on groundwater resources require stochastic modelling of potential recharge, but this has implications for groundwater model runtimes. It is recommended that stochastic modelling of potential recharge is used in vulnerable or sensitive groundwater systems, and that the multiple recharge time series are sampled according to the distribution of contextually important time series variables, e.g. recharge drought severity and persistence (for water resource management) or high recharge years (for groundwater flooding). Such an approach will underpin an improved understanding of climate change impacts on sustainable groundwater resource management based on adaptive management and risk-based frameworks.

Shah (2009) reviewed the India's opportunities for mitigation and adaptation with reference to climate change and groundwater. For millennia, India used surface storage and gravity flow to water crops. During the last 40 years, however, India has witnessed a decline in gravity-flow irrigation and the rise of a booming 'water-scavenging' irrigation economy through millions of small, private tubewells. For India, groundwater has become at once critical and threatened. Climate change will act as a force multiplier; it will enhance groundwater's criticality for drought-proofing agriculture and simultaneously multiply the threat to the resource. Groundwater pumping with electricity and diesel also accounts for an estimated 16–25 million mt of carbon emissions, 4–6% of India's total. From a climate change point of view, India's groundwater hotspots are western and peninsular India. These are critical for climate change mitigation as well as adaptation. To achieve both, India needs to make a transition from surface storage to 'managed aquifer storage' as the center pin of its water strategy with proactive demand- and supply-side management components. In doing this, India needs to learn intelligently from the experience of countries like Australia and the United States that have long experience in managed aquifer recharge.

Allen (2010) examined historical groundwater levels for selected observation wells in the south coastal region of British Columbia, Canada, to gain a better understanding of historical trends. Over a common period (1976-1999), negative trends in groundwater level dominate most records, and appear to be related to longer term negative regional trends in precipitation, although variable trends are evident at the shorter time periods used for this study. To explore potential consequences of varying recharge on groundwater quality, water chemistry data from selected monitoring wells on one island were examined. Chloride concentrations were observed to vary annually in one well by up to 4000 mg/L. Projections for future climate from one global climate model (CGCM1) were used as input to a recharge model to study the sensitivity of recharge to shifts in precipitation and temperature predicted for the region. The recharge model was driven by a stochastic daily weather series, calibrated to historic climate data. Daily weather series represent historic climate, and two future time periods (2020s) and (2050s). Simulated recharge increases progressively in the future using this particular global climate model; however, precipitation projections for this region of British Columbia are highly uncertain. Both positive and negative shifts in annual precipitation were predicted using a range of global climate models.

Allen et al. (2010) addressed variations in the prediction of recharge by comparing recharge simulated using climate data generated using a state-of-the-art downscaling method, TreeGen, with a range of global climate models (GCMs). The study site is the transnational Abbotsford- Sumas aquifer in coastal British Columbia, Canada and Washington State, USA, and is representative of a wet coastal climate. Sixty-four recharge zones were defined based on combinations of classed soil permeability, vadose zone permeability, and unsaturated zone depth (or depth to water table) mapped in the study area. One-dimensional recharge simulations were conducted for each recharge zone using the HELP hydrologic model, which simulates percolation through a vertical column. The HELP model is driven by mean daily temperature, daily precipitation, and daily solar radiation. For the historical recharge simulations, the climate data series was generated using the LARS-WG stochastic weather generator. Historical recharge was compared to recharge simulated using climate data series derived from the Tree-Gen downscaling model for three future time periods: 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) for each of four GCMs (CGCM3.1, ECHAM5, PCM1, and CM2.1). Recharge results are compared on an annual basis for the entire aquifer area. Both increases and decreases relative to historical recharge are simulated depending on time period and model. By the 2080s, the range of model predictions spans −10.5% to +23.2% relative to historical recharge. This variability in recharge predictions suggests that the seasonal performance of the downscaling tool is important and that a range of GCMs should be considered for water management planning.

Crosbie et al. (2010) presented a methodology for assessing the average changes in groundwater recharge under a future climate. The method is applied to the 1,060,000 km^2 Murray-Darling Basin (MDB) in Australia. Climate sequences were developed based upon three scenarios for a 2030 climate relative to a 1990 climate from the outputs of 15 global climate models. Dryland diffuse groundwater recharge was modelled in WAVES using these 45 climate scenarios and fitted to a Pearson Type III probability distribution to condense the 45 scenarios down to three: a wet future, a median future and a dry future. The use of a probability distribution allowed the significance of any change in recharge to be assessed. This study found that for the median future, climate recharge is projected to increase on average by 5% across the MDB but this is not spatially uniform. In the wet and dry future scenarios the recharge is projected to increase by 32% and decrease by 12% on average across the MDB, respectively. The differences between the climate sequences generated by the 15 different global climate models makes it difficult to project the direction of the change in recharge for a 2030 climate, let alone the magnitude.

Dams et al. (2010) presented a methodology to predict the potential impact of climate change on quantitative groundwater characteristics determining GWDTEs (Groundwater Dependent Terrestrial Ecosystems). The developed methodology includes coupling a distributed hydrological model (WetSpa) with a transient groundwater flow model (MODFLOW) and is tested for the Kleine Nete basin, Belgium. Because the occurrence of phreatophytes is strongly determined by the dynamic properties of the groundwater system, a groundwater flow model with a high temporal and spatial distribution was developed using MODFLOW. The groundwater recharge and river heads are estimated with the WetSpa model using a daily time step to incorporate the impact of changes in rainfall intensity. Potential future hydrological changes are calculated by comparing the hydrological state corresponding to 1960-1991 with future scenarios developed for 2070-2101.

Since the uncertainty in the prediction of the future climate components such as potential evapotranspiration (PET) and precipitation is still high, an ensemble of 28 climate scenarios were chosen from the PRUDENCE database. For each of these scenarios, recharge, river stage, groundwater head and groundwater flow are estimated for 32 years with half monthly time steps. Comparison of the original measured PET with future PET shows that the PET during summer rises in all future scenarios with about 1 mm per day. For winter conditions the scenarios predict little change in PET. Future precipitation shows an increase in precipitation during winter and a decrease during summer. Future groundwater recharge decreases on average with 20 mm per year, the highest decreases are simulated from July until September. Average groundwater heads indicate an average decrease of 7 cm. Groundwater levels in interfluves generally show decreases up to 30 cm. The mean lowest groundwater level decreases on average with 6 cm, while the mean highest groundwater level decreases about 3 cm. On average, the groundwater discharge reduces with 4%, from 5 to 4.8 m^3/s. GWDTEs that currently receive a low groundwater discharge, are likely to disappear due to future climate changes.

McCallum et al. (2010) used a sensitivity analysis of climate variables using a modified version of WAVES, a soil-vegetation-atmosphere-transfer model (unsaturated zone), to determine the importance of each climate variable in the change in groundwater recharge for three points in Australia. This study found that change in recharge is most sensitive to change in rainfall. Increases in temperature and changes in rainfall intensity also led to significant changes in recharge. Although not as significant as other climate variables, some changes in recharge were observed due to changes in solar radiation and carbon dioxide concentration. When these variables were altered simultaneously, changes in recharge appeared to be closely related to changes in rainfall; however, in nearly all cases, recharge was greater than would have been predicted if only rainfall had been considered. These findings have implications for how recharge is projected to change due to climate change.

Okkonen et al. (2010) presented a literature review of the impacts of anticipated climate change on unconfined aquifers, along with a conceptual framework for evaluating the complex responses of surface and subsurface hydrology to climate variables in cold regions. The framework offers a way to conceptualize how changes in one component of the system may impact another by delineating the relationships among climate drivers, hydrological responses, and groundwater responses in a straight-forward manner. The model is elaborated in the context of shallow unconfined aquifers in the boreal environment of Finland. In cold conditions, climate change is expected to reduce snow cover and soil frost and increase winter floods. The annual surface water level maximum will occur earlier in spring, and water levels will decrease in summer due to higher evapotranspiration rates. The maximum recharge and groundwater level are expected to occur earlier in the year. Lower groundwater levels are expected in summer due to higher evapotranspiration rates. The flow regimes between shallow unconfined aquifers and surface water may change, affecting water quantity and quality in the surface and groundwater systems.

Oude Essink et al. (2010) focussed on a coastal groundwater system that is already threatened by a relatively high seawater level: the low-lying Dutch Delta. Nearly one third of the Netherlands lies below mean sea level, and the land surface is still subsiding up to 1 m per century. This densely populated delta region, where fresh groundwater resources are used intensively for domestic, agricultural, and industrial purposes, can serve as a laboratory case for other low-lying delta areas throughout the world. Their findings on hydrogeological effects can be scaled up since the problems the Dutch face now will very likely be the problems encountered in other delta areas in the future. They calculated the possible impacts of future sea level rise, land subsidence, changes in recharge, autonomous salinization, and the effects of two mitigation counter-measures with a three-dimensional numerical model for variable density groundwater flow and coupled solute transport (MOCDENS3D). They considered the effects on hydraulic heads, seepage fluxes, salt loads to surface waters, and changes in fresh groundwater resources as a function of time and for seven scenarios.

Their numerical modeling results show that the impact of sea level rise is limited to areas within 10 km of the coastline and main rivers because the increased head in the groundwater system at the coast can easily be produced though the highly permeable Holocene confining layer. Along the southwest coast of the Netherlands, salt loads will double in some parts of the deep and large polders by the year 2100 A.D. due to sea level rise. More inland, ongoing land subsidence will cause hydraulic heads and phreatic water levels to drop, which may result in damage to dikes, infrastructure, and urban areas. In the deep polders more inland, autonomous upconing of deeper and more saline groundwater will be responsible for increasing salt loads. The future increase of salt loads will cause salinization of surface waters and shallow groundwater and put the total volumes of fresh groundwater volumes for drinking water supply, agricultural purposes, industry, and ecosystems under pressure.

Payne (2010) observed that sea-level rise and changes in precipitation patterns may contribute to the occurrence and affect the rate of saltwater contamination in the Hilton Head Island, South Carolina area. To address the effects of climate change on saltwater intrusion, a three-dimensional, finite-element, variable-density, solute-transport model (SUTRA 2.1) was developed to simulate different rates of sea-level rise and variation in onshore freshwater recharge. Model simulation showed that the greatest effect on the existing saltwater plume occurred from reducing recharge, suggesting recharge may be a more important consideration in saltwater intrusion management than estimated rates of sea-level rise. Saltwater intrusion management would benefit from improved constraints on recharge rates by using model-independent, local precipitation and evapotranspiration data, and improving estimates of confining unit hydraulic properties.

Rozell and Wong (2010) investigated the effects of climate change on Shelter Island, New York State (USA), a small sandy island, using a variable-density transient groundwater flow model (SEAWAT). Predictions for changes in precipitation and sea-level rise over the next century from the Intergovernmental Panel on Climate Change 2007 report were used to create two future climate scenarios. In the scenario most favorable to fresh groundwater retention, consisting of a 15% precipitation increase and 0.18-m sea-level rise, the result was a 23-m seaward movement of the freshwater/ salt-water interface, a 0.27-m water-table rise, and a 3% increase in the fresh-water lens volume. In the scenario supposedly least favorable to groundwater retention, consisting of a 2% precipitation decrease and 0.61-m sea-level rise, the result was a 16-m landward movement of the fresh-water/salt-water interface, a 0.59-m watertable rise, and a 1% increase in lens volume. The unexpected groundwater-volume increase under unfavorable climate change conditions was best explained by a clay layer under the island that restricts the maximum depth of the aquifer and allows for an increase in freshwater lens volume when the water table rises.

Vandenbohede and Lebbe (2010) evaluated the effects of sea level rise and future recharge changes on the coastal aquifer of the western Belgian coastal plain with a 3D density dependent groundwater flow model (MOCDENS3D). The area is characterised by a wide dune belt. Sea level rise results in a landward enlargement of the fresh water lens under the dunes and an increase of flow towards the dune-polder transition's drainage system. Recharge increase results also in an enlargement of the dune's fresh water lens and an increase of the amount of water which must be evacuated by the polder's drainage system. Recharge decrease has the reverse effect.

Zhou et al. (2010) reported that climate change affects not only water resources but also water demand for irrigation. A large proportion of the world's agriculture depends on groundwater, especially in arid and semi-arid regions. In several regions, aquifer resources face depletion. Groundwater recharge has been viewed as a by-product of irrigation return flow, and with climate change, aquifer storage of such flow will be vital. A general review, for a broadbased audience, is given of work on global warming and groundwater resources, summarizing the methods used to analyze the climate change scenarios and the influence of these predicted changes on groundwater resources around the world (especially the impact on regional groundwater resources and irrigation requirements). Future challenges of adapting to climate change are also discussed. Such challenges include water-resources depletion, increasing irrigation demand, reduced crop yield, and groundwater salinization. The adaptation to and mitigation of these effects is also reported, including useful information for water-resources managers and the development of sustainable groundwater irrigation methods. Rescheduling irrigation according to the season, coordinating the groundwater resources and irrigation demand, developing more accurate and complete modeling prediction methods, and managing the irrigation facilities in different ways would all be considered, based on the particular cases.

Barthel (2011) presented an integrated approach for assessing the availability of groundwater under conditions of 'global-change'. The approach is embedded in the DANUBIA system developed by the interdisciplinary GLOWA-Danube Project to simulate the interaction of natural and socio-economic processes within the Upper Danube Catchment (UDC, 77,000 km^2 and located in parts of Germany, Austria, Switzerland and Italy). The approach enables the quantitative assessment of groundwater bodies (zones), which are delineated by intersecting surface watersheds, regional aquifers, and geomorphologic regions. The individual hydrogeological and geometrical characteristics of these zones are accounted for by defining characteristic response times and weights to describe the relative significance of changes in variables (recharge, groundwater level, groundwater discharge, river discharge) associated with different states. These changes, in each zone, are converted into indices (*GroundwaterQuantityFlags*). The motivation and particularities of regional-scale groundwater assessment and the background of GLOWA-Danube are described, along with a description of the developed methodology. The approach was applied to the UDC, where several different climate scenarios (2011–2060) were evaluated. A selection of results is presented to demonstrate the potential of the methodology. The approach was inspired by the European Water Framework Directive, yet it has a stronger focus on the evaluation of global-change impacts.

Yihdego and Webb (2011) carried out modeling of bore hydrographs to determine the impact of climate and land-use change in a temperate subhumid region of southeastern Australia. To determine the relative impact of climate and human intervention on groundwater elevations in western Victoria, southeast Australia, bore hydrograph fluctuations in three aquifers were modelled using a transfer function noise model (PIRFICT) and an auto-regressive model (HARTT), which give generally comparable results. Most of the groundwater-level fluctuations (>90%) are explained by climatic variation, particularly rainfall. The overall non-climate-related trend in groundwater level is downward and small but statistically significant (−0.04 to −0.066 m/yr), and is probably due to the widespread replacement of grazing land by wheat and canola cultivation, as these crops use more water than pasture. A large non-climate-related trend (−0.30 m/yr) for bores in an irrigation area is mainly related to groundwater extraction. The response time of the system is rapid (only 4.85 years on average), much faster than previously estimated. Rates of groundwater flow are much slower; groundwater ages are up to ~35,000 years. Response times effectively represent the time for the system to move to a new state of hydrologic equilibrium; this prediction of the time scale of the impacts of land-use change on groundwater resources will allow the development of better strategies for groundwater management.

Crosbie et al. (2012) investigated episodic recharge with reference to climate change in the Murray-Darling Basin, Australia. In semi-arid areas, episodic recharge can form a significant part of overall recharge, dependant upon infrequent rainfall events. With climate change projections suggesting changes in future rainfall magnitude and intensity, groundwater recharge in semi-arid areas is likely to be affected disproportionately by climate change. This study sought to investigate projected changes in episodic recharge in arid areas of the Murray-Darling Basin, Australia, using three global warming scenarios from 15 different global climate models (GCMs) for a 2030 climate. Two metrics were used to investigate episodic recharge: at the annual scale the coefficient of variation was used, and at the daily scale the proportion of recharge in the highest 1% of daily recharge. The metrics were proportional to each other but were inconclusive as to whether episodic recharge was to increase or decrease in this environment; this is not a surprising result considering the spread in recharge projections from the 45 scenarios. The results showed that the change in the low probability of exceedance rainfall events was a better predictor of the change in total recharge than the change in total rainfall, which has implications for the selection of GCMs used in impact studies and the way GCM results are downscaled.

Neukum and Azzam (2012) investigated the impact of climate change on groundwater recharge in a small catchment in the Black Forest, Germany. Temporal and spatial changes of the hydrological cycle are the consequences of climate variations. In addition to changes in surface runoff with possible floods and droughts, climate variations may affect groundwater through alteration of groundwater recharge with consequences for future water management. This study investigates the impact of climate change, according to the Special Report on Emission Scenarios (SRES) A1B, A2 and B1, on groundwater recharge in the catchment area of a fissured aquifer in the Black Forest, Germany, which has sparse groundwater data. The study uses a water-balance model considering a conceptual approach for groundwater-surface water exchange. River discharge data are used for model calibration and validation. The results show temporal and spatial changes in groundwater recharge. Groundwater recharge is progressively reduced for summer during the twenty-first century. The annual sum of groundwater recharge is affected negatively for scenarios A1B and A2. On average, groundwater recharge during the twenty-first century is reduced mainly for the lower parts of the valley and increased for the upper parts of the valley and the crests. The reduced storage of water as snow during winter due to projected higher air temperatures causes an important relative increase in rainfall and, therefore, higher groundwater recharge and river discharge.

Raposo et al. (2013) assessed the impact of future climate change on groundwater recharge in Galicia-Costa, Spain. Climate change can impact the hydrological processes of a watershed and may result in problems with future water supply for large sections of the population. Results from the FP5 PRUDENCE project suggest significant changes in temperature and precipitation over Europe. In this study, the Soil and Water Assessment Tool (SWAT) model was used to assess the potential impacts of climate change on groundwater recharge in the hydrological district of Galicia-Costa, Spain. Climate projections from two general circulation models and eight different regional climate models were used for the assessment and two climate-change scenarios were evaluated. Calibration and validation of the model were performed using a daily time-step in four representative catchments in the district. The effects on modeled mean annual groundwater recharge are small, partly due to the greater stomatal efficiency of plants in response to increased CO_2 concentration. However, climate change strongly influences the temporal variability of modeled groundwater recharge. Recharge may concentrate in the winter season and dramatically decrease in the summer–autumn season. As a result, the dry-season duration may be increased on average by almost 30% for the A2 emission scenario, exacerbating the current problems in water supply.

Lapworth et al. (2013) estimated residence times of shallow groundwater in West Africa. Although shallow groundwater (<50 mbgl) sustains the vast majority of improved drinking-water supplies in rural Africa, there is little information on how resilient this resource may be to future changes in climate. This study presents results of a groundwater survey using stable isotopes, CFCs, SF_6, and ^3H across different climatic zones (annual rainfall 400–2,000 mm/year) in West Africa. The purpose was to quantify the residence times of shallow groundwaters in sedimentary and basement aquifers, and investigate the relationship between groundwater resources and climate. Stable-isotope results indicate that most shallow groundwaters are recharged rapidly following rainfall, showing little evidence of evaporation prior to recharge. Chloride mass-balance results indicate that within the arid areas (<400 mm annual rainfall) there is recharge of up to 20 mm/year. Age tracers show that most groundwaters have mean residence times (MRTs) of 32–65 years, with comparable MRTs in the different climate zones. Similar MRTs measured in both the sedimentary and basement aquifers suggest similar hydraulic diffusivity and significant groundwater storage within the shallow basement. This suggests there is considerable resilience to short-term inter-annual variation in rainfall and recharge, and rural groundwater resources are likely to sustain diffuse, low volume abstraction.

Mollema and Antonellini (2013) investigated seasonal variation in natural recharge of coastal aquifers. Many coastal zones around the world have irregular precipitation throughout the year. This results in discontinuous natural recharge of coastal aquifers, which affects the size of freshwater lenses present in sandy deposits. Temperature data for the period 1960–1990 from LocClim (local climate estimator) and those obtained from the Intergovernmental Panel on Climate Change (IPCC) SRES A1b scenario for 2070–2100, have been used to calculate the potential evapotranspiration with the Thornthwaite method. Potential recharge (difference between precipitation and potential evapotranspiration) was defined at 12 locations: Ameland (The Netherlands), Auckland and Wellington (New Zealand); Hong Kong (China); Ravenna (Italy), Mekong (Vietnam), Mumbai (India), New Jersey (USA), Nile Delta (Egypt), Kobe and Tokyo (Japan), and Singapore. The influence of variable/discontinuous recharge on the size of freshwater lenses was simulated with the SEAWAT model. The discrepancy between models with continuous and with discontinuous recharge is relatively small in areas where the total annual recharge is low (258–616 mm/year); but in places with Monsoon-dominated climate (e.g. Mumbai, with recharge up to 1,686 mm/year), the difference in freshwater-lens thickness between the discontinuous and the continuous model is larger (up to 5 m) and thus important to consider in numerical models that estimate freshwater availability.

These studies are still at infancy and more data, in terms of field information are to be generated. This will also facilitate appropriate validation of the simulation for the present scenarios. In summary, climate change is likely to have an impact on future recharge rates and hence on the underlying groundwater resources. The impact may not necessarily be a negative one, as evidenced by some of the investigations. Quantifying the impact is difficult, however, and is subject to uncertainties present in the future climate predictions. Simulations based on general circulation models (GCMs) have yielded mixed and conflicting results, raising questions about their reliability in predicting future hydrologic conditions. However, it is clear that the global warming threat is real and the consequences of climate change phenomena are many and alarming.

Methodology to Assess the Impact of Climate Change on Groundwater Resources

The potential impacts of climate change on water resources have long been recognized although there has been comparatively little research relating to groundwater. The principle focus of climate change research with regard to groundwater has been on quantifying the likely direct impacts of changing precipitation and temperature patterns. Such studies have used a range of modelling techniques such as soil water balance models, empirical models, conceptual models and more complex distributed models, but all have derived changes in groundwater recharge assuming parameters other than precipitation and temperature remaining constant.

There are two main parameters that could have a significant impact on groundwater levels: recharge and river stage/discharge. To assess the impact on the groundwater system to changes in these two parameters, it is necessary to have a calibrated flow model and to conduct a sensitivity analysis by varying these two parameters and calculating changes to the water balance (e.g., differences in water levels). The research objectives can be:

- To develop a conceptual model of the hydrogeology of the study region;
- To investigate how regional and local weather events affect recharge;
- To determine potential impacts of climate change on recharge for the study area, and to assess the sensitivity of the results to different global climate models;
- To develop and calibrate a regional-scale three-dimensional groundwater flow model of the region and to use that model to assess the impacts of climate change on groundwater resources; and
- To develop and calibrate a local-scale three-dimensional groundwater flow model, and to undertake a well capture zone analysis for the local community water supply wells for the region.

The methodology consists of three main steps. To begin with, climate scenarios can be formulated for the future years such as 2050 and 2100. This is done by assigning percentage or value changes of climatic variables on a seasonal and/or annual basis only for the future years relative to the present year. Secondly, based on these scenarios and present situation, seasonal and annual recharge, evapotranspiration and runoff are simulated with the WHI UnSat Suite (HELP module for recharge) and/or WetSpass model. Finally, the annual recharge outputs from WHI UnSat Suite or WetSpass model are used to simulate groundwater system conditions using steady-state MODFLOW model setups for the present condition and for the future years.

The main tasks that are involved in such a study are:

1. Describe hydrogeology of the study area.
2. Undertake a statistical analysis to separate climate into regional and local events and determine the role of each in contributing to groundwater recharge.
3. Analyze climate data from weather stations and modelled GCM, and build future predicted climate change datasets with temperature, precipitation and solar radiation variables.
4. Define methodology for estimating changes to recharge in the model under both current climate conditions and for the range of climate-change scenarios for the study area.
5. Use of a computer code (such as WHI UnSat Suite or WetSpass) to estimate recharge based on available precipitation and temperature records and anticipated changes to these parameters.
   A. **Recharge estimation by WHI UnSat Suite:** UnSat Suite contains the sub-

program, Visual HELP, which contains a more user-friendly interface for the program HELP that is approved by the United States Environmental Protection Agency (US EPA) for designing landfills. Visual HELP enables the modeler to generate estimates of recharge using a weather generator and the properties of the aquifer column.

B. **Recharge estimation by WetSpass:** WetSpass is a quasi physically distributed seasonal-water balance model, which takes into account detailed soil, land-use, slope, groundwater depth, and hydro-climatological distributed maps with associated parameter tables for estimating groundwater recharge. The model uses seasonal (summer and winter) geographical information systems (GIS) input grids of the mentioned inputs to estimate annual and seasonal groundwater recharge values.

6. Quantify the spatially distributed recharge rates using the climate data and spatial soil survey data.
7. Development and calibration of a three-dimensional regional-scale groundwater flow model (such as Visual MODFLOW). Since one of the inputs required for WetSpass is the groundwater depth data, which is predicted with the MODFLOW model, an interface may be developed in an ArcView GIS platform to couple the two models, facilitating exchange of data between the two models. The coupled WetSpass-MODFLOW model is run for the present situation and for each of the climate change scenarios on an annual basis.
8. Simulate groundwater flow using each recharge data set and evaluate the changes in groundwater flow and levels through time.
9. Undertake sensitivity analysis of the groundwater flow model.
10. Develop a local scale groundwater model for the specific study area and conduct a well capture zone analysis.

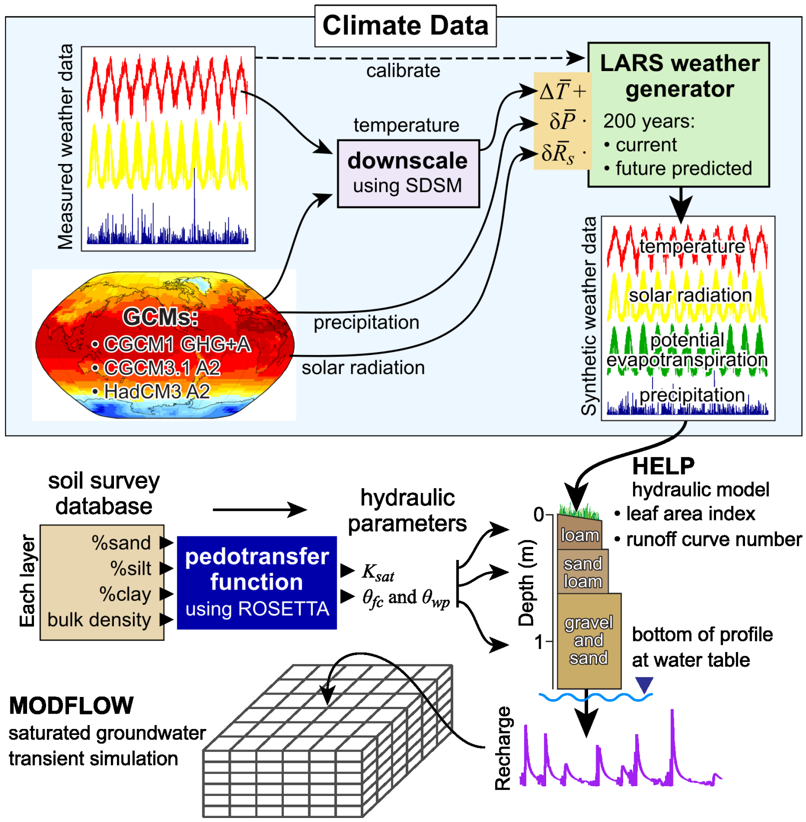
A typical flow chart for various aspects of such a study is shown in Figure 2. The figure shows the connection from the climate analysis, to recharge simulation, and finally to a groundwater model. Recharge is applied to a three-dimensional groundwater flow model, which is calibrated to historical water levels. Transient simulations are undertaken to investigate the temporal response of the aquifer system to historic and future climate periods.

Tasks in the upper part of the chart assemble several climate data sets for current and future predicted conditions, which are used to simulate recharge using HELP module of WHI UnSat Suite. The soil layers are parameterized using a pedotransfer function program, which utilizes detailed soil survey measurements. Mapped monthly recharge from HELP is then used in a three-dimensional MODFLOW model to simulate transient saturated groundwater flow.

FUTURE RESEARCH DIRECTIONS

Although climate change has been widely recognized, research on the impacts of climate change on the groundwater system is relatively limited. The reasons may be that long historical data are required to analyze the characteristics of climate change. These data are not always available. Also, the driving forces that cause such changes are yet unclear. The climatic abnormality may occur frequently and last for a period of time. Even if the required data exist, uncertainty is embedded in model parameters, structure and driving force of the hydrological cycle. Predicting the long-term effect of a dynamic system is very difficult because of limitations inherent in the models, and the unpredictability of the forces that drive the earth. A physically based model of a groundwater system

Figure 2. Flow chart of tasks (Toews, 2007)



under possible climate change based on available data is very important to prevent the deterioration of regional water-resource problems in the future. Although uncertainties are inevitable, new response strategies in water resource management based on the model may be useful.

Precipitation is commonly downscaled in climate change impact studies; however, the reliability of the downscaled result is often poor or unreliable, as there is often little correlation between the predictors and the predictands. A poor correlation is often attributed to mesoscale processes occurring at the site-scale that are not represented in regional models due to their representative spatial and temporal sizes in comparison to larger-scale regional precipitation. Mesoscale precipitation processes generally occur in the summer season in the form of convective clouds, which are a result of local-scale evapotranspiration from elevated temperatures and solar radiation magnitudes. As a result, global-scale models may underestimate the summer precipitation measured at a site.

A number of Global Climate Models (GCM) are available for understanding climate and projecting climate change. There is a need to downscale GCM on a basin scale and couple them with relevant hydrological models considering all components of the hydrological cycle. Output of these coupled models such as quantification of the groundwater recharge will help in taking appropriate adaptation strategies due to the impact of climate change.

CONCLUSION

The investigation of the relationship between climate change and loss of fresh groundwater resources is important for understanding the characteristics of the different regions. The impact of future climatic change may be felt more severely in developing countries such as India, whose economy is largely dependent on agriculture and is already under stress due to current population increase and associated demands for energy, freshwater and food. In spite of the uncertainties about the precise magnitude of climate change and its possible impacts, particularly on regional scales, measures must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects.

Groundwater recharge is influenced not only by hydrologic processes, but also by the physical characteristics of the land surface and soil profile. Many climate change studies have focused on modelling the temporal changes in the hydrologic processes and ignored the spatial variability of physical properties across the study area. While knowing the average change in recharge and groundwater levels over time is important, these changes will not occur equally over a regional catchment or watershed. Long-term water resource planning requires both spatial and temporal information on groundwater recharge in order to properly manage not only water use and exploitation, but also land use allocation and development. Studies concerned with climate change should therefore also consider the spatial change in groundwater recharge rates.

If the likely consequences of future changes of groundwater recharge, resulting from both climate and socio-economic change, are to be assessed, hydrogeologists must increasingly work with researchers from other disciplines, such as socio-economists, agricultural modelers and soil scientists.

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KEY TERMS AND DEFINITIONS

Aquifer: An underground layer of permeable rock which can contain or transmit water.

Groundwater: Water held underground in soil pore spaces and fractures of rock formations.

Hydrological Cycle: Describes the continuous movement of water on, above and below the surface of earth.

IPCC: The IPCC (Intergovernmental Panel on Climate Change) is a scientific intergovernmental body which assesses the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change.

MODFLOW: U.S. Geological Survey modular finite-difference flow model (computer code) that solves the groundwater flow equation to simulate the flow of groundwater through aquifers.

Numerical Model: Mathematical model using some sort of numerical time-stepping procedure to obtain the model's behavior over time.

Recharge: A hydrologic process where water moves downward from surface water to groundwater.

Seawater Intrusion: The movement of seawater into fresh water aquifers due to natural processes or human activities.

Soil Moisture: The water stored in the upper soil layer.

UnSat Suite: Software package for one-dimensional unsaturated flow and transport modeling using SESOIL, VLEACH, PESTAN, VS2DT and HELP.

Chapter 11
Assessment of Annual, Monthly, and Seasonal Trends in the Long Term Rainfall of the Garhwal Himalayas

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ABSTRACT

Climate change is one of the very significant apprehension argued in the recent two decades. Its influence on rainfall has brought in considerable attention worldwide. Hence, this chapter focuses on assessing the trends in the rainfall during 1901-2012 in the Dehradun, Haridwar, Uttarkashi, Tehri-Garhwal, Pauri-Garhwal, Rudraprayag and Chamoli districts of the Garhwal Himalayas by applying non-parametric Mann-Kendall and the Theil-Sen's Slope Estimator tests for the determination of trend and its magnitude. The findings revealed a statistically significant positive trend in annual and monthly rainfall (May and July) of Dehradun district. Rainfall shows a statistically significant positive trend in May (Haridwar and Tehri Garhwal) and a significant negative trend in January (Uttarkashi and Chamoli). On the other hand, Pauri Garhwal and Rudraprayag indicates no significant trend in monthly rainfall. An insignificant trend has also been observed in seasonal rainfall of most of the districts. Annual, monthly and seasonal rainfall shown no particular pattern in the region.

INTRODUCTION

One of the most important concerns confronting the world is undoubtedly the threat of climate change as it is expected to alter regional hydrologic conditions and could impact the water resource systems. There are many indicators of climate change such as changes in surface temperature, changes in atmospheric water vapor, changes in precipitation, changes in severe events, and changes in glaciers, changes in the ocean and land ice and changes in sea level. The latest report of the Intergovernmental Panel on Climate Change (IPCC, 2013) mentioned that the global combined land and ocean temperature data has increased about 0.89°C during 1901-2012 and 0.72°C during

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1950-2012. It also mentioned that the Northern Hemisphere mid-latitude land areas show a likely overall increase in precipitation.

Climate change is expected to evident quite significantly in India also as it would induce changes in the complexion, distribution, quality and functionality of the natural resource base. Further, it would result in 'insecure livelihoods' due to disruptions in the social, cultural, economic, ecological systems, physical infrastructure and human assets; increasing health risks, and crippling or even negating the developmental gains and opportunities (State Action Plan on Climate Change, 2012). The study of rainfall trends is critically important for a country like India, whose food security and economy are dependent on the timely availability of water. In India, attempts have been made in the past to determine trends in the rainfall at national and regional scales. Naidu, Rao, and Rao (1999) studied the trends and periodicities of annual rainfall for 29 sub-divisions of India by using the rainfall series for a period of 124 years (1871-1994). A negative trend is seen over west central India, central north India and north-eastern parts of India. A positive tendency is present over north-west India, covering Haryana, Punjab, and East Rajasthan, West Rajasthan and West Madhya Pradesh, an isolated area in the east Gangetic West Bengal and the peninsula. Guhathakurta and Rajeevan (2008) constructed monthly, seasonal and annual rainfall time series of 36 meteorological subdivisions of India for the period 1901–2003. It has been found that the contribution of June, July and September rainfall to annual rainfall is decreasing for few subdivisions while the contribution of August rainfall is increasing in few other subdivisions. Kumar, Jain, and Singh (2010) also studied the similar trends in rainfall for the period of 1871-2005 for 30 sub-divisions (sub-regions) in India. For the whole of India, no significant trend was detected for annual, seasonal, or monthly rainfall. Annual and monsoon rainfall decreased, while pre-monsoon, post-monsoon and winter rainfall increased at the national scale. Pal and Al-Tabbaa (2010) found that the rainfall in June, July and September decreased, whereas in August it increased at the national scale. It was shown that there are decreasing trends in the spring and monsoon rainfall and increasing trends in the autumn and winter rainfalls over the period of 1954-2003. Several researchers (Rai, Upadhyay, & Ojha, 2010; Kumar & Jain, 2011; Jain & Kumar, 2012; Rana, Uvo, Bengtsson, & Sarthi, 2012; Mondal, Kundu, & Mukhopadhyay, 2012 ; Ratna, 2012; Babar & H., 2013) have contributed to the study of climate change with long term data in India and found that trend is either positive or negative in case of rain. Some researchers have indicated that the climate change was one of the causes for the Uttarakhand tragedy (DobhalL, Gupta, Mehta, & Khandelwal, 2013; Srinivasan, 2013).

Review of literature revealed a lack of studies in the assessment of trends in the rainfall of Uttarakhand Himalayas. Thus, in this chapter, an effort has been made to study the inter-annual and intra-seasonal variability in rainfall of the period 1901-2012 in districts (Dehradun, Haridwar, Tehri Garhwal, Uttarkashi, Chamoli, Pauri Garhwal and Rudraprayag) of the Garhwal division of Uttarakhand. Research questions of the study - Are there any changes in annual/seasonal/monthly rainfall in the districts? If there are changes, what are the patterns of the changes, i.e. whether the changes are showing a positive or negative trend? What is the magnitude of the trend? In which months/seasons do they happen?

STUDY AREA

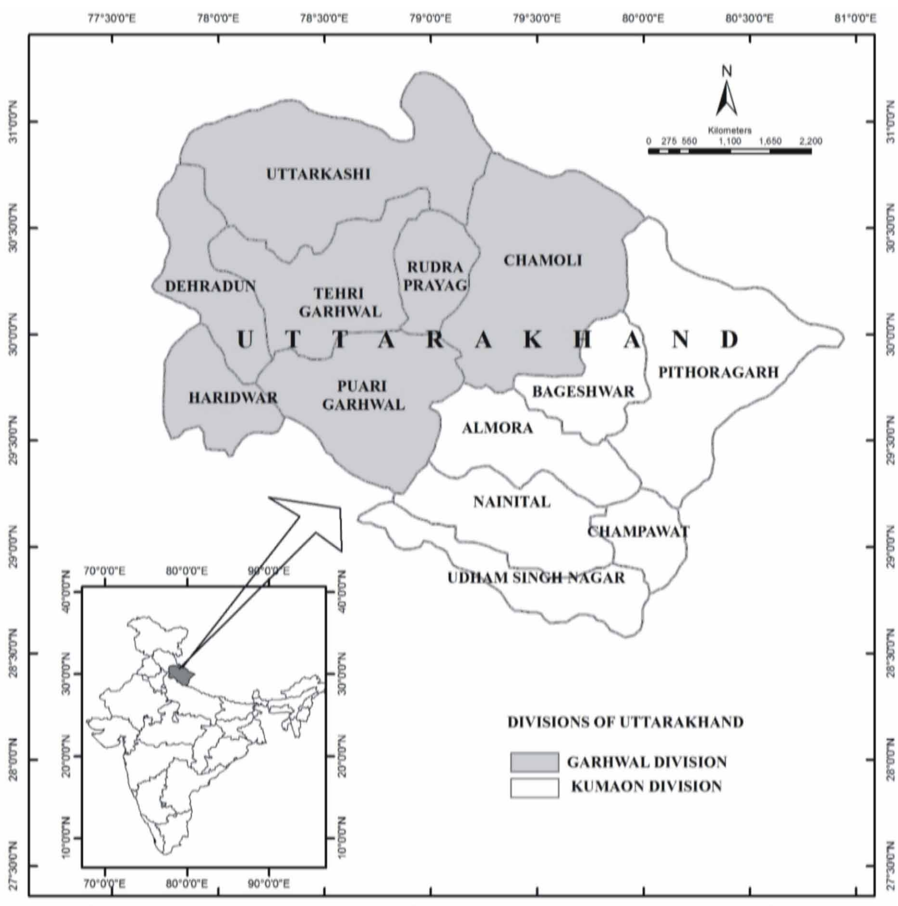
Uttarakhand state is in the northern region of India. The latitudinal and longitudinal extent of the state is 28°43' N to 31°27' N and 77°34' E to 81°02' E respectively (Figure 1). Area of the state is 53,483 km^2, out of which 86% area is hilly and the remaining area is plain. According to the 2011 census of India, Uttarakhand has a population of 10.1 lakh, making it the 19^{th} most populous state in India. There are 13 districts in Uttarakhand, which are grouped into two divisions, Kumaon and Garhwal. The Kumaon division includes the district of Almora, Bageshwar, Champawat, Nainital, Pithoragarh, Udham Singh Nagar and the Garhwal division includes the districts of Dehradun, Haridwar, Tehri Garhwal, Uttarkashi, Chamoli, Pauri Garhwal and Rudraprayag. Present study includes districts of Garhwal Himalayas in Uttarakhand because this was the region which faced disaster in 2013 due to heavy rain.

The mean monthly air temperature of the state varies from -4.0° C to 37.9° C. Average rainfall in the state is 1843 mm. About ¾ of the total rainfall is confined to the monsoon season and remaining ¼ occurs in the other seasons due to the western disturbances and local orographic effects. The monsoonal activities generally begin in the latter part of June and extents in the month of September.

MATERIALS AND METHODS

The monthly rainfall data of the last 110 years (1901-2012) of the districts of Dehradun, Haridwar, Uttarkashi, Tehri Garhwal, Pauri Garhwal, Rudraprayag and Chamoli of the Garhwal Himalayan division of Uttarakhand were collected from India Meteorological Department.

Figure 1. Location of the study area



Descriptive statistics (mean, standard deviation and coefficient of variation) were used to characterize the rainfall. Percentage departures in the annual/monthly rainfall were computed as follows.

$$\frac{R_c - R_r}{R_r} \times 100$$

where,

R_c = Annual/Monthly rainfall of the current year
R_r = normal annual/monthly rainfall of the reference period

Percentage departures in monthly rainfall is computed only monsoon season as it contributes about 85% to the annual rainfall. Standard normal of annual/monthly rainfall of the period 1961-1990 were computed from the data to get the percentage departures in the annual/monthly rainfall. Trend analysis of rainfall time series data has carried out by applying non-parametric Mann-Kendall test. This method is being applied to study the temporal trends of hydro-climatic series. It was chosen over the parametric test because it does not require the data to be normally distributed and has low sensitivity to abrupt breaks due to inhomogeneous time series. It means, any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set. This test had been formulated by Mann (1945) as non-parametric test for trend detection and Kendall (1975) had given the test statistic distribution for testing non-linear trend and turning point. The null hypothesis H_0 (which assumes that there is no trend) is tested against the alternative hypothesis H_1, which assumes that there is a trend (Onoz & Bayazit, 2003). The computational procedure for the Mann Kendall test considers the time series of n data points and T_i and T_j as two subsets of data where i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n. The data values are measured as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. If the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S (Drápela & Drápelová, 2011). The Mann-Kendall S Statistic is computed as follows:

$$\mathrm{S} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\left(Tj - Ti\right)$$

$$sign\left(Tj - Ti\right) = \begin{Bmatrix} 1 \; if \; Tj - Ti > 0 \\ 0 \; if \; Tj - Ti = 0 \\ -1 \; if \; Tj - Ti < 0 \end{Bmatrix}$$

where, Tj and Ti are the annual values in years j and i, j >i, respectively (Motiee and McBean, 2009). For n ≥10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E\left(s\right) = 0$$

The variance (sd (S) ^{2}) for the S statistics is given as:

$$sd\left(S\right)^2 = \frac{n\left(n-1\right)\left(2n+5\right) - \sum ti\left(i\right)\left(i-1\right)\left(2i+5\right)}{18}$$

where ti denotes the number of ties to extent i. The summation term in the numerator is used only when the data series contains tied values. The standard test statistic Z_s is calculated as follows:

$$Z_s = \begin{cases} \dfrac{s-1}{\sigma} \; for S > 0 \\ 0 \; for \; S = 0 \\ \dfrac{s+1}{\sigma} \; for \; S < 0 \end{cases}$$

The test statistic Z_s is using a measure of significance of trends. In fact, this test statistic is used to test the null hypothesis, H0. If $|Z_s|$ is greater than Zα/2, where α represents the chosen significance level (e.g.: 5% with Z 0.025 = 1.96) then the null hypothesis is invalid implying that the trend is significant (Motiee & McBean, 2009).

Theil-Sen's Slope Estimator is also used to estimate the direction and magnitude of the trend. This test is also a non-parametric trend test. It is considered over the parametric test because it does not affected by the outliers present in the data. This test was given by Theil (1950) and Sen (1968). This test can be used in cases where the trend can be assumed to be linear. Theil-Sen's trend line is computed with the following equation:

$$f\left(t\right) = Qt + B$$

where f (t) is a continuous monotonic increasing or decreasing function of time and Q is the slope and B is a constant. Determine the Theil-Slope estimate, Q, as the median value of this set of N ordered slopes. Computation of the median slope depends on whether N is even or odd. The median slope is computed using the following algorithm-

$$Qi = \frac{x_j - x_k}{j - k} \text{ For i=1, 2 … N}$$

where x_j and x_k are data values at time j and k {j > k) respectively. The median of these N values of T, is Sen's estimated of slope which is calculated as

$$Q = \begin{cases} T_{(N+1)/2} & if\ N\ is\ odd \\ \frac{\left(T_{N/2} + \mathrm{T}_{(N+2)/2}\right)}{2} & if\ N\ is\ even \end{cases}$$

A positive value of Q indicates an upwards (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Following hypotheses is tested in the Theil-Sen slope estimator test: Null hypothesis, H0: *Time series data set does not exhibit any trend*, vs. the alternative hypothesis, H1: *data set exhibits an upward (downward) trend.* For specified level of significance, α (0.05 and 0.01), compute the following-

$$C_a = Z_a \times sd\left(S\right)$$

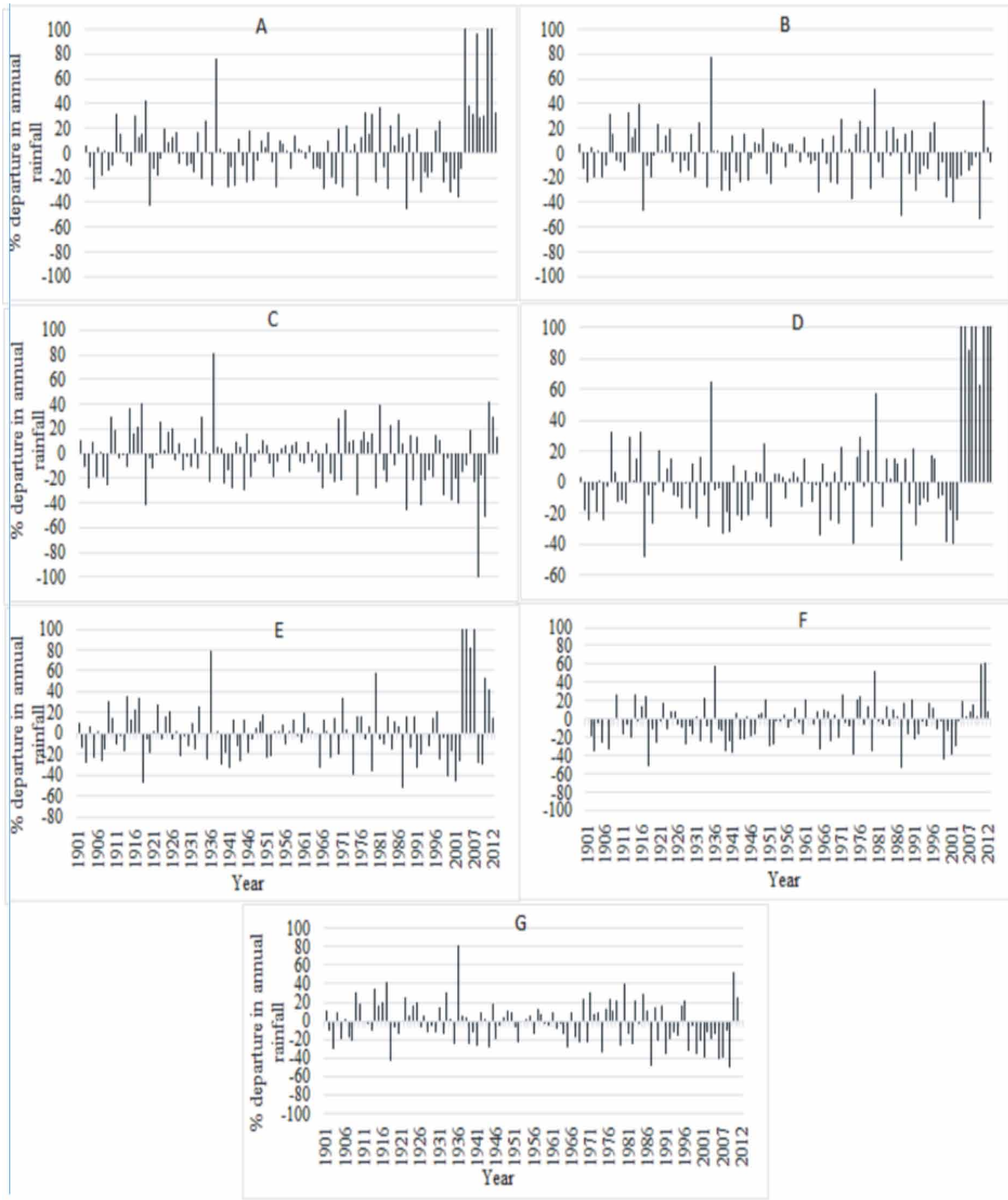
where C_a is confidence interval, sd(S) has been defined in equation (1) above, and Z_a is obtained from the normal distribution. Again compute $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ and the lower and upper limits of the confidence interval, Q_{min} and Q_{max}, are the M_1 th largest and the $(M_2 + 1)^{th}$ largest of the set consisting of all n(n-1)/2 slopes. If M_1 th largest is greater than 0, then the data set exhibits a significant upward trend. If $(M_2 + 1)^{th}$ largest is smaller than 0, then the data set exhibits a significant downward trend. To identify the changes, the rainfall series are subjected to 10-year moving averages to show some epochs.

RESULTS AND DISCUSSIONS

Epochal Variations of the Annual/Monthly Rainfall

To examine the epochs of above and below normal rainfall, % departures of rainfall from the long period averages of rainfall for the district were considered by taking normal annual rainfall of the districts for the period 1961-1990. The excess or deficient years of rainfall are defined for those years when annual rainfall percentage departures from the normal rainfall are more than ±20%. These epochs of above and below normal rainfall are shown in Figure 2. Rainfall in all the districts was above normal for most of the year during 1901-2012. During 1901-2012, Uttarkashi had 22 deficient and 21 excess rainfall years. Tehri

Figure 2. % departure in annual rainfall from normal annual rainfall (A- Uttarkahi, B- Tehri-Garhwal, C-Chamoli, D- Dehradun, E-Pauri-Garhwal, F-Haridwar and G-Rudraprayag)



Garhwal, Chamoli and Haridwar had 22, 24 and 25 deficient rainfall years respectively during the same period. All these three districts had 15 excess years. Dehradun had 23 deficient and 20 excess rainfall years. Pauri Garhwal had 24 deficient and 17 excess rainfall years. Rudraprayag had 26 deficient and 16 excess rainfall years. It indicates that the number of deficient rainfall years is higher than excess rainfall years in all the districts during the period of analysis. Deficient rainfall years has increased from 1991 in Chamoli, Pauri Garhwal and Rudraprayag are indicating more drought years, whereas excess rainfall years have increased since 1991 in Dehradun and Uttarkashi districts indicating frequent floods. It shows that mentioned districts had often faced extreme weather events since 1991 compared to other districts in Garhwal region of Uttarakhand.

In case of percentage departures of monthly rainfall from normal rainfall, all the districts of the Garhwal division have often experienced deficient rainfall years, then the excess rainfall years (Figure 3) during 1901-2012. These districts have also experienced maximum deficient rainfall years in September during the period of analysis. It indicates more frequent drought like condition in September. Chamoli, Pauri Garhwal, Tehri Garhwal and Rudraprayag districts faced frequent deficient rainfall from July to September during the period 1961-1990 compared to the period 1991-2012. In contrast, excess rainfall frequency has increased in Dehradun from July to September since 1991. Similarly, Uttarkashi has also frequent excess rainfall since 1991 but from July to August. Haridwar has shown a decrease in both deficient and excess rainfall events from July to September since 1991. This shows that the north Garhwal division districts have experienced frequent excess rainfall events then deficient rainfall events. On the other hand, these conditions are opposite in the south Garhwal division districts.

Intra and Inter Annual Trends in Rainfall

Average annual rainfall received at Dehradun district was 1000.8 mm and mean monthly rainfall in the district varied from 298.8 mm in July to 6.3 mm in November during the 1901-2012 (Table 1). Coefficient of variation of rainfall shows highest variation (146%) in November and lowest variation (51.3%) in July (Table 1). A statistically significant increasing trend in the district was observed in May and July at the rate of 0.115 mm/year and 0.88 mm/year, respectively (Table 1), indicates high intensity of change in rainfall in July. It suggests that the district would receive high rain in July in the long run, if the observed rate of alteration in the amount of rainfall continues to prevail at the standardized rate. Likewise, annual rainfall of the district has also shown statistically significant increasing trend at the rate of 1.71 mm/year (Table 1), which is consistent with the previous study done in the area (Basistha, et al., 2009). This trend is probably due to increase in mean air temperature. Singh et al. (2013) found an increase of roughly 0.43^{0}C, 0.38^{0}C and 0.49^{0}C in annual maximum, minimum and mean temperatures respectively during 1901-2012 in the city of Dehradun. The 10-year moving average in annual rainfall in the district showed one period of fall (1984-2001) and one period of rise (2001-2012) during 1901-2012 (Figure 4), indicating warming in the last decade.

During 1901-2012, the districts of Haridwar and Tehri-Garhwal received mean annual rainfall of 839 mm and 1017.9 mm respectively (Table 2 and 3). Coefficient of variation of rainfall of both the districts indicates highest variation in November and lowest in August during the period of analysis (Table 2 and 3). Monthly rainfall at both the districts indicates statistically significant increasing trend in May at the rate of 0.13 and 0.12 mm/year, respectively (Table 2 and 3). Though the

Figure 3. % departure in monthly rainfall from normal monthly rainfall (A- Uttarkahi, B- Tehri-Garhwal, C-Chamoli, D- Dehradun, E-Pauri-Garhwal, F-Haridwar and G-Rudraprayag)

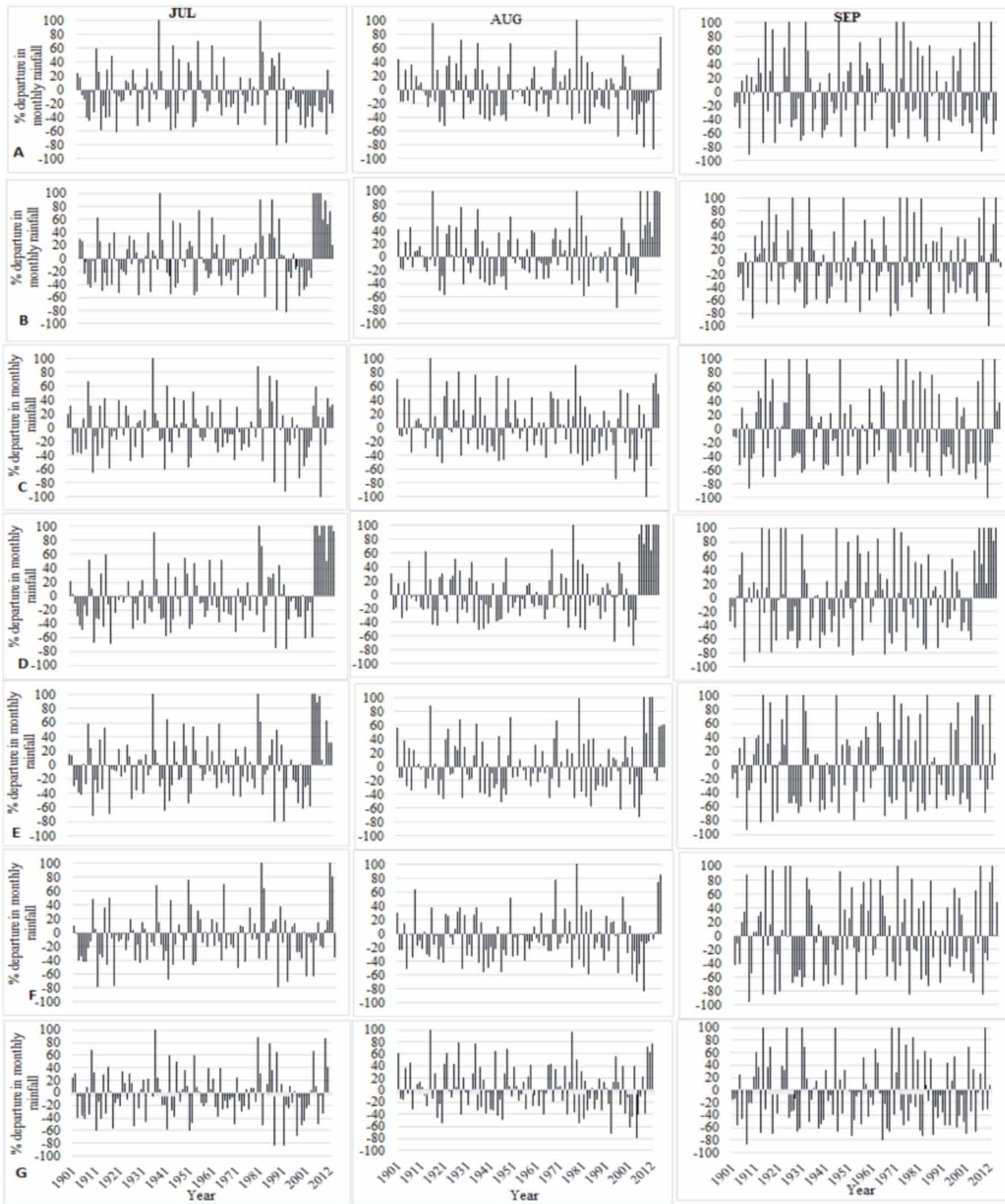
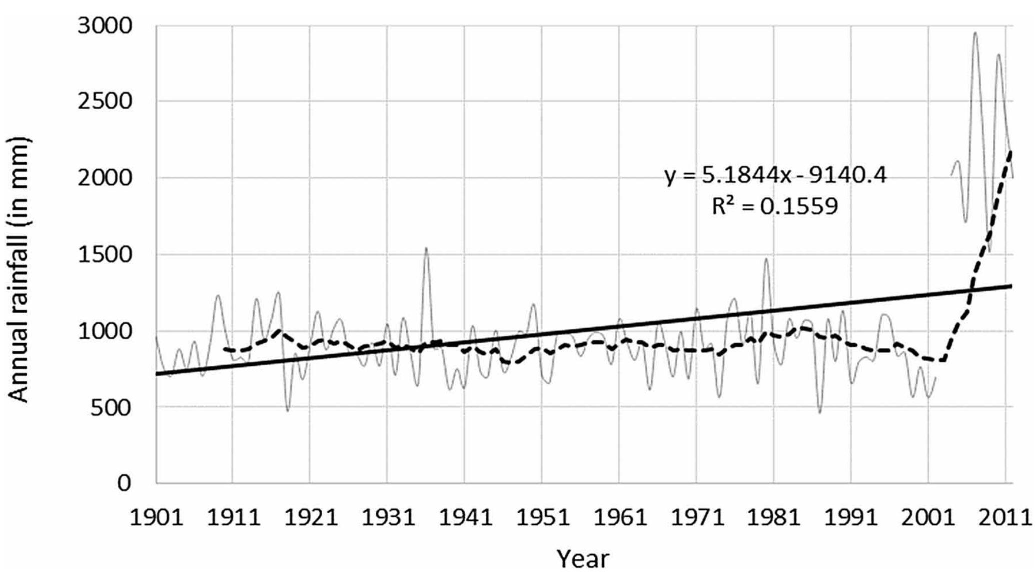


Table 1. Descriptive statistics and trend in rainfall of the Dehradun district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	28.4	21.7	76.4	-1.111	-0.066	No trend
Feb	27.6	21.8	79.0	1.246	0.069	No trend
Mar	20.9	20.3	97.1	1.31	0.056	No trend
Apr	14.2	11.7	82.4	0.948	0.023	No trend
May	24.3	22.0	90.5	2.339*	0.115*	positive
Jun	104.5	80.2	76.7	1.116	0.189	No trend
Jul	298.8	153.3	51.3	2.309*	0.883*	positive
Aug	297.8	155.2	52.1	1.682	0.576	No trend
Sep	149.2	120.2	80.6	1.855	0.453	No trend
Oct	18.1	22.3	123.2	0.963	0.029	No trend
Nov	6.3	9.2	146.0	0.0284	0	No trend
Dec	10.9	12.5	114.7	-0.895	-0.013	No trend
Annual	1000.8	424.4	42.4	2.13*	1.718*	positive
*Significant at 0.05 level **Significant at 0.01 level						

Figure 4. Trend in annual rainfall of the Dehradun district



magnitude of change in the amount of rainfall is low in comparison to Dehradun district, but a slight rise in the rainfall could have a serious effect on the river run-off. It could make the area vulnerable to water related hazards. Moreover, these trends are matters of discourse as these are taking place in the month of the pre-monsoon season. Further, excess rainfall could also contribute to soil saturation as well as runoff and soil erosion problems. Hence, it is of vast importance to discuss the ecological, economic and societal impacts that could result if increasing rainfall trends continue in the hereafter. Yearly rainfall in both the districts has shown insufficient evidence to identify a trend (Table 2 and 3). Time series curve of annual rainfall in the district of Haridwar showed one period of fall (1997-2002) and one period of rise (2004-2012) during 1901–2012 (Figure 5). However, annual rainfall in the district of Tehri-Garhwal showed one period of continuous decline during 1985-2010 (Figure 6).

Mean annual rainfall occurred in Uttarkashi and Chamoli districts are 1058.4 mm and 1133.1 mm, respectively during 1901-2012 (Table 4 and 5), indicating high rainfall due to high altitude region. Coefficient of variation of rainfall at both the districts indicates highest variation in November and lowest in August during the period of analysis (Table 4 and 5) which is similar to observed variation in rainfall of districts of Haridwar and Tehri-Garhwal. Both the districts shown a statistically significant decreasing trend in rainfall in January at the rate of -0.161 mm/year (Uttarkashi) and -0.136 mm/year (Chamoli) (Table 4 and 5). It would imply a decrease in river discharge, thereby contributing to a reduction of water supply for power generation and irrigation in January. Annual rainfall in the district has not shown sufficient evidence to detect a trend during the period of observation (Table 4 and 5). Annual rainfall in the district of Uttarkashi showed one period of major fall (1987-2001) and one period

Table 2. Descriptive statistics and trend in rainfall of the Haridwar district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	23.1	18.1	78.4	-1.131	-445	No trend
Feb	22.4	22.7	101.3	0.449	0.022	No trend
Mar	16.7	16.7	100.0	1.226	0.037	No trend
Apr	11.6	10.7	92.2	0.339	0.008	No trend
May	20.0	15.4	77.0	2.734**	0.13**	positive
Jun	82.5	52.2	63.3	0.805	0.098	No trend
Jul	247.5	96.9	39.2	1.131	0.269	No trend
Aug	259.1	94.0	36.3	0.438	0.12	No trend
Sep	127.2	80.0	62.9	0.543	0.145	No trend
Oct	15.3	16.7	109.2	0.112	0.002	No trend
Nov	5.6	8.6	153.6	0.437	0	No trend
Dec	9.0	10.8	120.0	-0.12	0	No trend
Annual	839.0	190.9	22.8	1.713	1.041	No trend

*Significant at 0.05 level
**Significant at 0.01 level

Table 3. Descriptive statistics and trend in rainfall of the Tehri Garhwal district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	30.6	0.0	0.0	-0.795	-0.051	No trend
Feb	32.6	27.3	83.7	0.775	0.052	No trend
Mar	23.9	19.9	83.3	1.241	0.056	No trend
Apr	17.6	12.6	71.6	0.892	0.032	No trend
May	30.9	19.9	64.4	1.975*	0.12*	positive
Jun	115.0	69.0	60.0	-0.78	-0.132	No trend
Jul	289.7	113.5	39.2	-1.264	-0.44	No trend
Aug	287.9	105.0	36.5	-1.289	-0.38	No trend
Sep	148.5	89.1	60.0	-0.556	-0.14	No trend
Oct	22.9	24.7	107.9	-0.107	-0.003	No trend
Nov	6.4	9.3	145.3	-0.893	-2.469	No trend
Dec	12.0	13.7	114.2	-0.55	-0.006	No trend
Annual	1017.9	224.4	22.0	-1.065	-0.726	No trend
*Significant at 0.05 level **Significant at 0.01 level						

Figure 5. Trend in annual rainfall of the Haridwar district

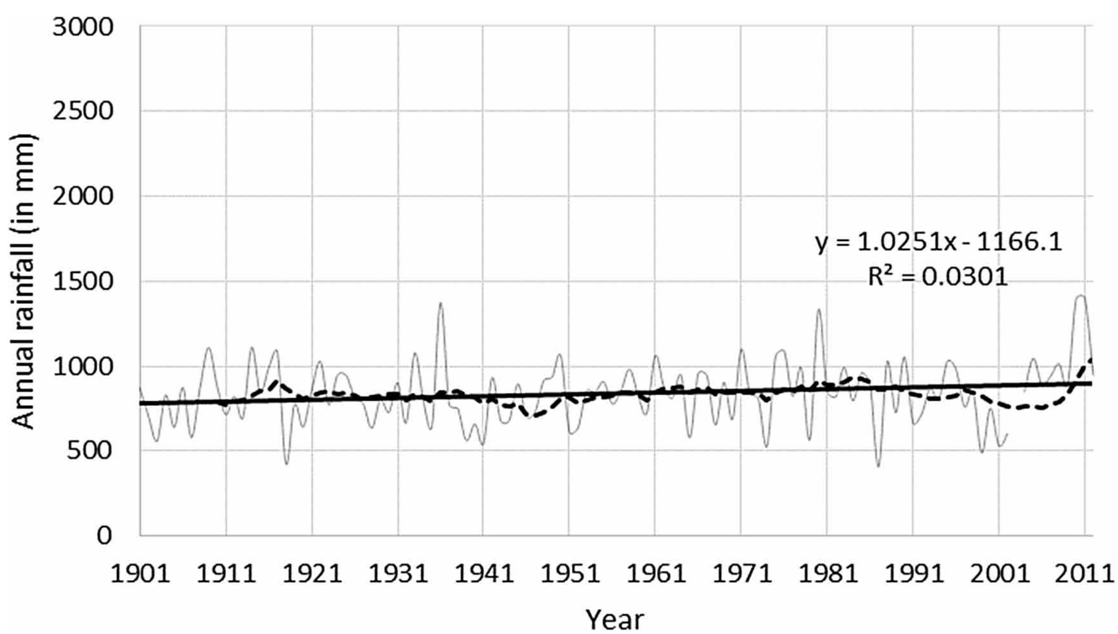
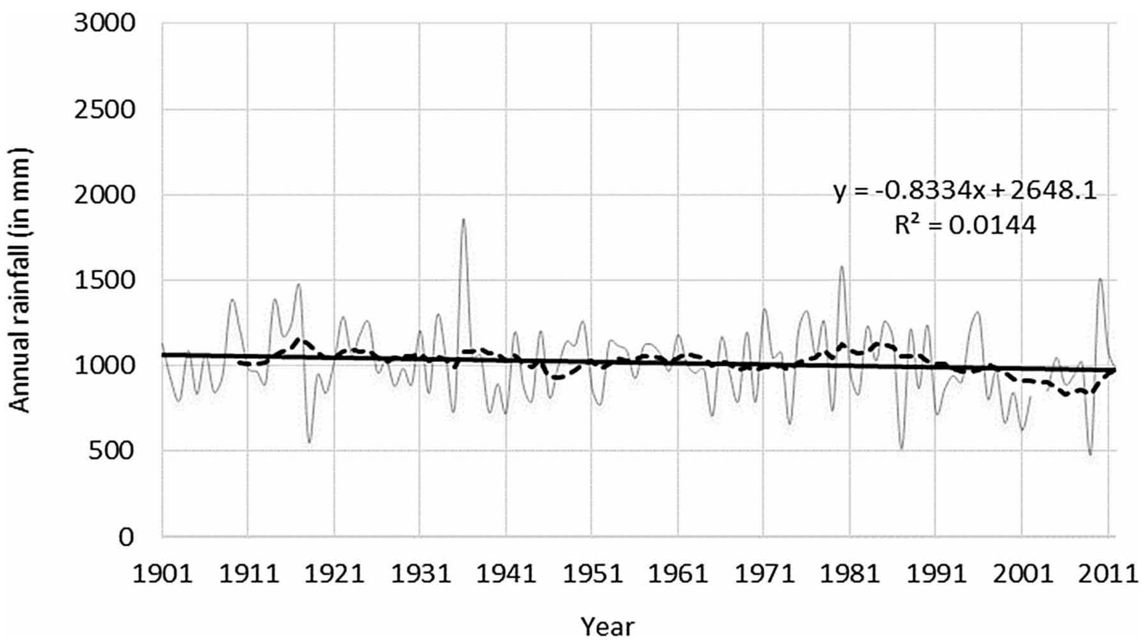


Figure 6. Trend in annual rainfall of the Tehri Garhwal district



of the rise (2002-2012) (Figure 7). On the other hand, Chamoli district has shown several short periods of increasing and decreasing trend in the annual rainfall. Last decade shown a fall in annual rainfall of the Chamoli district (Figure 8). This indicates fall in annual rainfall at both the districts during last decade.

Average annual rainfall in the district of Pauri Garhwal and Rudraprayag was 1051.4 mm and 1101.6 mm, respectively during 1901-2012 (Table 6 and 7). Like other districts, coefficient of variation of rainfall of both the districts also indicates highest variation in November and lowest in August during the period of analysis (Table 6 and 7). The district of Pauri Garhwal and Rudraprayag for all the months indicates no significant trend (Table 6 and 7), means more stability in rainfall at both the districts, compared to other districts during 1901-2012. Annual rainfall at both the districts has also shown an insignificant trend during the period of analysis (Table 6 and 7). However, the 10-year moving average in annual rainfall in the district of Pauri Garhwal showed one period of the rise (1984-2002) and one period of fall (2002-2012) (Figure 9). Like the Chamoli district, Rudraprayag district showed several periods of ups and downs averages of the annual rainfall (Figure 10).

Intra-Seasonal Trends in Rainfall

The seasonal dynamics of rainfall pattern were also tested using a scheme for seasons adapted from a previous study (Jain, et al., 2009). The seasons include winter (December to March), pre-monsoon (April to June), monsoon (July to September) and post-monsoon season (October and November). Table 8 revealed that all the districts received highest mean rainfall during monsoon season followed by pre monsoon, winter and post monsoon season during 1901-2012. Coefficient of variability indicates high variability in the rainfall during the post-monsoon season while least during the monsoon season in almost all the districts. Chamoli and Rudraprayag districts are showing a statistically significant decreasing trend at the rate of 0.35 mm/year and 0.36 mm/year, respectively

Table 4. Descriptive statistics and trend in rainfall of the Uttarkashi district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	34.3	27.3	79.6	-2.329*	-0.161*	negative
Feb	37.3	29.3	78.6	-0.981	-0.067	No trend
Mar	30.6	24.1	78.8	-0.0754	-0.002	No trend
Apr	25.0	20.1	80.4	-1.242	-0.061	No trend
May	36.6	28.5	77.9	-0.543	-0.042	No trend
Jun	125.8	81.1	64.5	-0.256	-0.036	No trend
Jul	296.2	153.4	51.8	1.214	0.476	No trend
Aug	283.1	145.8	51.5	0.596	0.195	No trend
Sep	145.8	94.1	64.5	-0.141	-0.043	No trend
Oct	24.0	25.1	104.6	-0.41	-0.014	No trend
Nov	8.9	13.0	146.1	-1.065	-0.002	No trend
Dec	13.2	15.1	114.4	-1.695	-0.029	No trend
Annual	1058.4	324.3	30.6	1.129	0.971	No trend

*Significant at 0.05 level
**Significant at 0.01 level

Table 5. Descriptive statistics and trend in rainfall of the Chamoli district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	34.7	27.8	80.1	-2.02*	-0.136*	negative
Feb	40.5	30.8	76.0	-0.404	-0.04	No trend
Mar	34.5	26.0	75.4	0.611	0.041	No trend
Apr	28.7	21.4	74.6	-1.195	-0.070	No trend
May	43.6	31.0	71.1	-0.23	-0.016	No trend
Jun	137.0	85.8	62.6	-0.765	-0.194	No trend
Jul	302.0	113.2	37.5	0.325	0.125	No trend
Aug	296.3	108.4	36.6	-0.852	-0.289	No trend
Sep	162.0	101.5	62.7	-0.403	-0.097	No trend
Oct	34.9	39.9	114.3	-1.028	-0.049	No trend
Nov	7.2	10.8	150.0	-1.645	-0.004	No trend
Dec	14.0	16.6	118.6	-1.444	-0.023	No trend
Annual	1133.1	253.3	22.4	-1.126	-0.986	No trend

*Significant at 0.05 level
**Significant at 0.01 level

Figure 7. Trend in annual rainfall of the Uttarkashi district

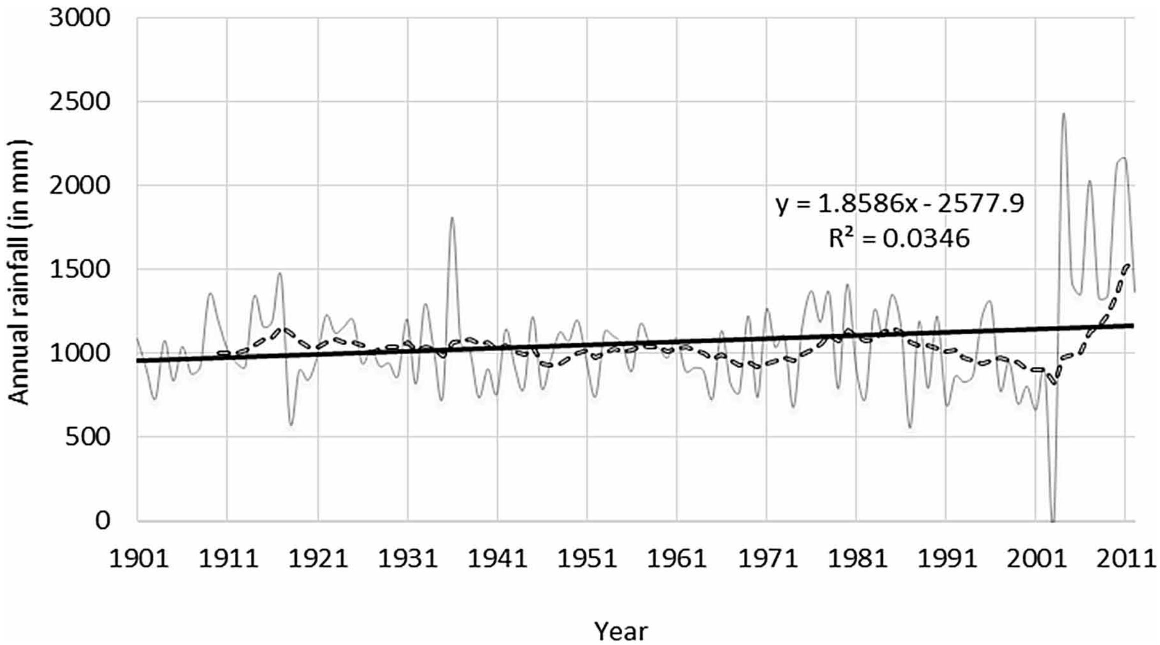


Figure 8. Trend in annual rainfall of the Chamoli district

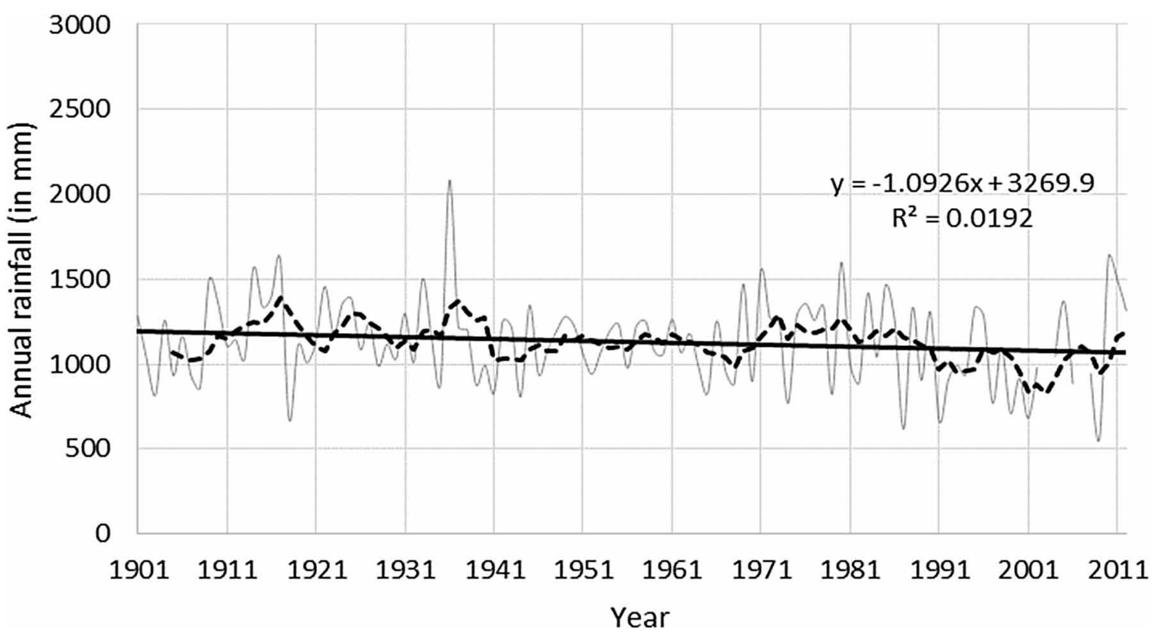


Table 6. Descriptive statistics and trend in rainfall of the Pauri Garhwal district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	25.4	20.5	80.7	-0.83	-0.046	No trend
Feb	26.9	28.1	104.5	0.688	0.041	No trend
Mar	19.6	16.4	83.7	1.394	0.056	No trend
Apr	13.9	11.3	81.3	-0.474	-0.013	No trend
May	28.7	30.0	104.5	1.747	0.101	No trend
Jun	115.3	75.0	65.0	0.423	0.094	No trend
Jul	306.4	145.8	47.6	1.075	0.4	No trend
Aug	319.2	138.9	43.5	0.642	0.23	No trend
Sep	159.0	107.7	67.7	0.668	0.186	No trend
Oct	25.9	33.2	128.2	-0.27	-0.007	No trend
Nov	4.3	6.4	148.8	-0.124	0	No trend
Dec	9.9	11.9	120.2	-0.56	-0.003	No trend
Annual	1051.4	353.7	33.6	0.408	0.362	No trend

Table 7. Descriptive statistics and trend in rainfall of the Rudraprayag district

Months	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Jan	37.2	27.6	74.2	-0.689	-0.055	No trend
Feb	40.4	30.4	75.2	0.0443	0.002	No trend
Mar	32.7	24.6	75.2	0.606	0.043	No trend
Apr	27.0	19.4	71.9	-0.656	-0.04	No trend
May	42.4	28.2	66.5	0.706	0.049	No trend
Jun	135.5	85.8	63.3	-0.469	-0.102	No trend
Jul	299.6	117.0	39.1	-0.0357	-0.030	No trend
Aug	291.2	109.0	37.4	-1.004	-0.301	No trend
Sep	157.6	95.4	60.5	-0.403	-0.107	No trend
Oct	31.3	35.3	112.8	-0.963	-0.041	No trend
Nov	7.6	11.1	146.1	-0.567	-8.197	No trend
Dec	14.1	16.3	115.6	-0.972	-0.014	No trend
Annual	1101.6	254.1	23.1	-1.697	-1.398	No trend

Figure 9. Trend in annual rainfall of the Pauri Garhwal district

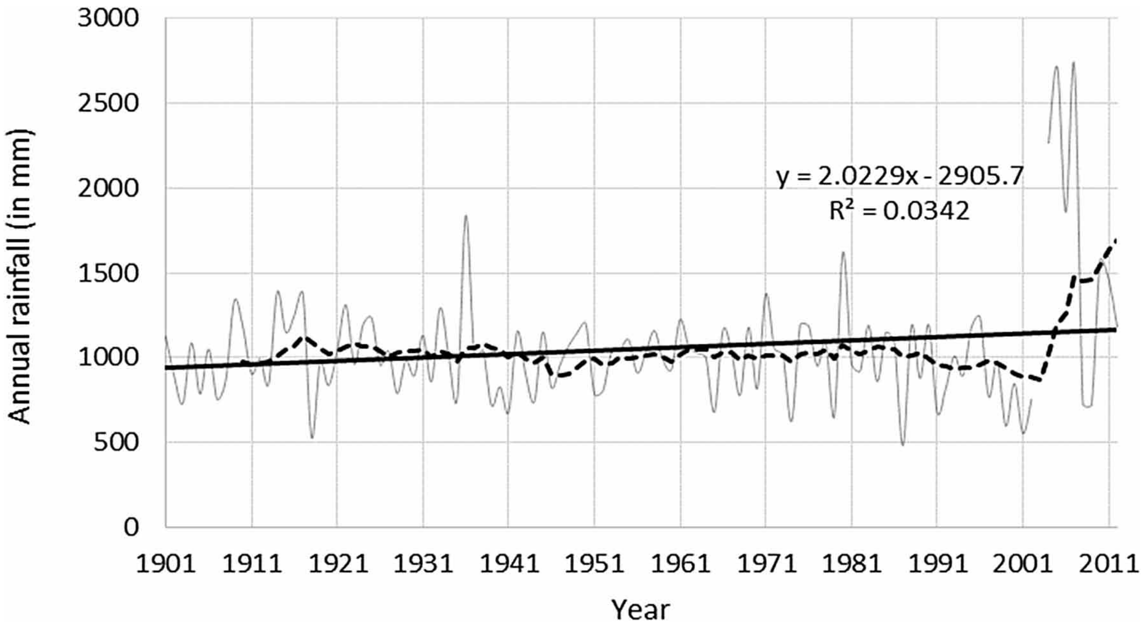
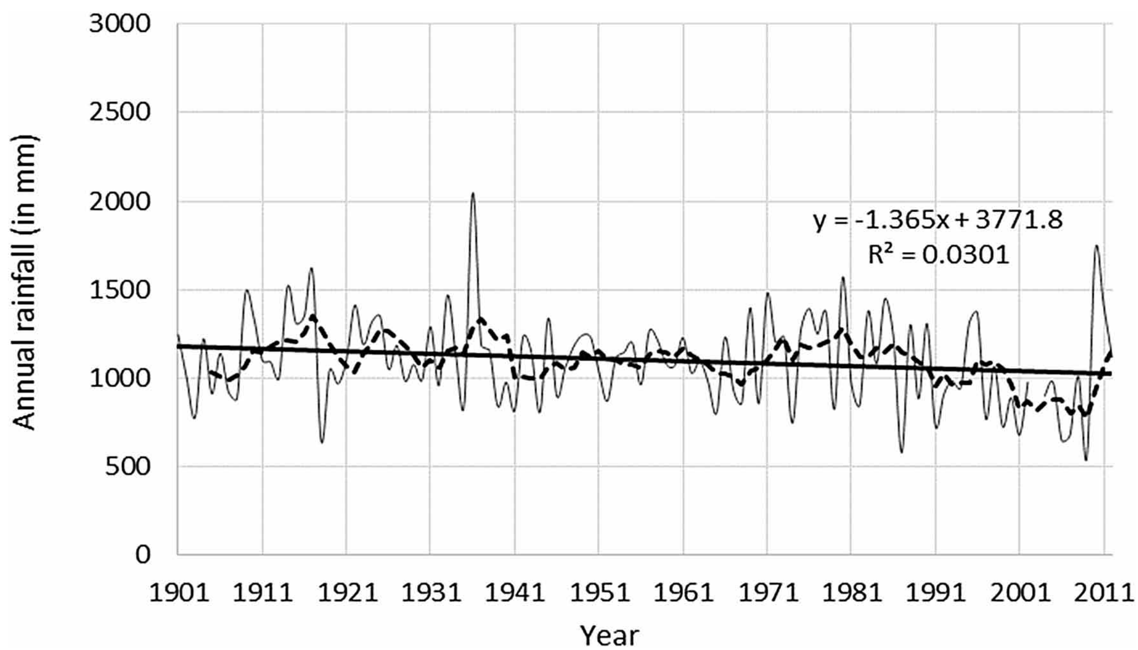


Figure 10. Trend in annual rainfall of the Rudraprayag district



while remaining districts shown no significant trend in seasonal rainfall during the period 1901-2012 (Table 8). The results are inconsistent with a previous study (Basistha, et al., 2009) that has found decreasing trend in monsoon rainfall of all stations located in the Garhwal Uttarakhand for the period 1902-1980. Differences in the results might be because of different periods.

Changes in climate are evident for centuries. Hence, the change in climate is part of nature, but if changes cross the certain limit, then it could have serious influences on the natural resources of the region. It is hard to find out the precise reasons of changes in rainfall. Several researchers have taken up just about causes for changes in rainfall. Basistha, et al. (2009) has mentioned three broad probable causes of change in rainfall. These are listed as follows:

1. Global climate shift or weakening global monsoon circulation.
2. Reduction in forest cover and change in land use, including the introduction of irrigated farming.
3. Increasing aerosol due to anthropogenic activities.

Uttarkhand state is vulnerable and fragile as this form part of the world's youngest mountain range; and also prone to erosion, landslides and seismic action and brutal rainstorms. The decade distribution of the extreme one-day rainfalls over the Himalayas shows a considerable increase in the frequencies during the decades 1951-1960 to 1991-2000, whereas there is a sudden decrease in the frequencies in the present decade during 2001-2007, indicating the need to understand the response of the systems to global change and the associated physical and climatological changes (Nandargi & Dhar, 2011). Though, the present work found evidences of increasing and decreasing trend in rainfall with low magnitude in the districts, but these trends could have serious impacts on natural resources in the area which would influence the river flow and affect the livelihood of the population in the upstream and downstream. Negi, et al., (2012) has given an overview of climate change impacts on agriculture, water and forest ecosystems in the western Himalayan Mountains based on literature review and some anecdotal evidences. They observed that a great deal of research work has been carried out on different aspects of western Himalayan mountain ecosystems, but the findings have yet to be correlated in the context of climate change. Further, there is a need to strengthen climate data collection network, which is presently insufficient to meet the requirement of climate change research. Moreover, there is also need to do a detailed study of the climate variables as mountain climate system is overly complex.

CONCLUSION

The present study analyzed the rainfall data for 110 years (1901-2012) of the districts of Dehradun, Haridwar, Tehri Garhwal, Uttarkashi, Chamoli, Pauri Garhwal and Rudraprayag in Uttarakhand for the determination of the direction and magnitude of the trend. Annual rainfall indicates statistically significant increasing trend in May and July in Dehradun. Monthly rainfall indicates statistically significant increasing trend in May at Haridwar and Tehri-Garhwal. On the other hand, Uttarkashi and Chamoli have shown statistically significant decreasing trend in rainfall in January. Pauri Garhwal and Rudraprayag districts for all the months indicates no significant trend. Seasonal rainfall in Chamoli and Rudraprayag districts is showing statistically significant decreasing trend, while remaining districts are showing no significant trend during the period 1901-2012. Overall, high altitude districts show more variability in the rainfall compared to low altitude districts. Therefore, it can be concluded that there are evi-

Table 8. Descriptive statistics and trend in seasonal rainfall of all districts

District/Season	Mean (mm)	Std. Deviation (mm)	CV (%)	Mann-Kendall Test (Z)	Sen's Slope (mm/yr)	Test Interpretation
Uttarkashi						
Winter	115	52	45.2	-1.32	-0.21	No trend
Pre-Monsoon	187	94	50.3	0.53	0.13	No trend
Monsoon	851	325	38.2	0.82	0.73	No trend
Post-Monsoon	33	27	81.8	-0.82	-0.05	No trend
Tehri-Garhwal						
Winter	98	44	44.9	0.08	0.01	No trend
Pre-Monsoon	162	79	48.8	0.10	0.02	No trend
Monsoon	834	230	27.6	-1.92	-1.23	No trend
Post-Monsoon	29	25	86.2	-0.51	-0.03	No trend
Chamoli						
Winter	120	54	45.0	-2.13*	-0.35*	negative
Pre-Monsoon	205	104	50.7	-1.54	-0.40	No trend
Monsoon	881	263	29.9	-1.37	-0.96	No trend
Post-Monsoon	41	40	97.6	-1.56	-0.11	No trend
Dehradun						
Winter	87	38	43.7	0.07	0.01	No trend
Pre-Monsoon	142	96	67.6	1.71	0.30	No trend
Monsoon	843	406	48.2	1.69	1.28	No trend
Post-Monsoon	24	23	95.8	0.41	0.02	No trend
Pauri-Garhwal						
Winter	79	41	51.9	-0.96	-0.09	No trend
Pre-Monsoon	156	90	57.7	0.67	0.14	No trend
Monsoon	892	332	37.2	0.26	0.22	No trend
Post-Monsoon	30	33	110.0	-0.82	-0.03	No trend
Haridwar						
Winter	71	38	53.5	-0.80	-0.07	No trend
Pre-Monsoon	113	61	54.0	1.56	0.24	No trend
Monsoon	710	201	28.3	0.74	0.44	No trend
Post-Monsoon	20	18	90.0	-0.39	-0.01	No trend
Rudraprayag						
Winter	117	55	47.0	-2.19*	-0.36*	negative
Pre-Monsoon	199	102	51.3	-1.06	-0.27	No trend
Monsoon	876	254	29.0	-1.31	-0.92	No trend
Post-Monsoon	38	36	94.7	-1.47	-0.10	No trend

*Significant at 0.05 level
**Significant at 0.01 level

dences of trend in monthly and seasonal rainfall in the state during last century, though there are intra-regional variations in the magnitude of trend.

Solutions and Recommendations

This study focused on rainfall variability, but climate variability also includes other climate variables such as air temperature, rainfall, snowfall, wind speed and direction, relative humidity. Hence, the study recommends to assess the variability in the mentioned climate variables, if their data are available, for understanding the changing behavior of the complex climate system of an area like Himalayas. Several statistical techniques (parametric and non-parametric trend tests) are available for trend analysis of climate variables, but there is need to understand the nature of data to apply appropriate techniques for meaningful interpretation of the outcomes. It is also essential to link the direction and magnitude of the trend with the geographical traits of the meteorological stations to understand the cause and effect relationship as geographical factors such as location, relief, aspect etc. plays significant role in influencing the climate system of the an area.

FUTURE RESEARCH DIRECTIONS

The study mentioned the variability in the rainfall at regional scale. There is a research opportunity to understand the micro climate variability by assessing the station level data over the time, so that the micro climate influencing factors can be taken into consideration to understand the complex climate system of the region like the Himalayas.

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Section 5

Fishery

Chapter 12
Impacts of Climate Change on Fish Productivity:
A Quantitative Measurement

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ABSTRACT

This paper attempts to understand the climatic and socio-economic factors influencing the efficiency and thereby the livelihood of fishing community in Mumbai. Efficiency in fishing is influenced by the scale of production, technology and inputs used, socio-economic and climate sensitive factors such as temperature, current, wind, rainfall etc. A primary survey of 164 fishing households is conducted in five fishing villages of Mumbai to collect input-output and other relevant data related to socioeconomic and climatic factors. Using stochastic frontier function, it is found that the number of working days, fuel costs, number of workers along with type of family, education, electronic gadgets used in fishing and observation on temperature change significantly affects the productivity and thereby their preparedness. The fishermen belonging to nuclear family and using advanced fishing equipments along with those are observing a rise in temperature successfully adapted and their efficiency level is increased. Mostly rich and affluent fishermen are more efficient than others. The estimated technical efficiencies for the fishing households range from 0.12 to 0.87, with a mean efficiency level of 0.39. Technological advancement in the production process with large scale of operation significantly influences fishermen's awareness, adaptability to climate change and also the efficiency.

1. INTRODUCTION

Climate change is a global social, environmental, economic and political problem. The actions to combat with the problem of climate change will not only affect current generation but also future generations. It has caught the attention of politicians, research funding agencies, (Bardsley and Wiseman, 2012) and the researchers. The greenhouse gas emission is projected to rise

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continuously, indicating that climate change is unavoidable and some of its impacts are irreversible (IPCC, 2007). There has been disagreement about causes of climate change and its varied effects. Nations with large population depending on natural resources and more exposed to the effects of climate change, weak institutional mechanism, and lack of infrastructural facilities are less likely to cope with the effects of climate change and thus are highly vulnerable.

Fishery is one of those sectors which is highly vulnerable to climate change and the livelihood of fishermen is at stake. It affects the fish distribution and thereby redistributes fishing efforts. The rise in sea level has a number of biophysical and socio-economic impacts (Nicholls and Lowe, 2004). Degradation of coastal ecosystems has seriously impacted the well-being of the communities dependent on the coastal ecosystems. Increased flooding and degradation of freshwater, fisheries and other resources could have enormous socio-economic impacts on millions of resource deficient vulnerable communities. It may lead to low productivity, low income, starvation, poor health as well as poor standard of living of the fishermen (Adebo and Ayelari, 2011). Fishing supports livelihood through fish production, processing and marketing activities. Over a period of time fishing operations are changing from subsistence based traditional occupation to profit oriented business, which is resulted into better livelihoods than before but also seriously threaten traditional skills, knowledge, and employment of artisanal fishermen (FAO, 2006). The diffusion of new technologies has benefited large scale fishermen primarily and leaving others behind.

In this paper we attempt to understand the climatic and socio-economic factors which influence the fish productivity and thereby the livelihood of fishing community in Mumbai. We find efficiencies and the factors affecting efficiencies of fish production process in Mumbai region by using stochastic frontier function. Both the functional forms, Cobb-Douglas production function and translog production function are used to derive the robustness in the analysis. This paper has been arranged in six sections. Section two gives brief account of climate change and coastal, ecological degradation and pollution in Mumbai and its coastal community. Section three discusses objectives, methods and materials. Section four goes through preliminary observations. Section five analyses the results and Section six concludes and provides policy implications.

2. CLIMATE CHANGE, ECOLOGICAL DEGRADATION, AND POLLUTION IN MUMBAI

2.1. Temperature

The A2 (business as usual) and B2 (sustainable path) scenarios are predicted for an average annual temperature increase of 1.75^{o}C and 1.25^{o}C respectively by 2050 for Mumbai (Sherbinin et al., 2007). Temperatures for the months of March to May have been increasing. In 2011 the highest temperature 41.6 ^{0}C was recorded for Mumbai.

2.2. Rainfall and Floods

On an average, annual 2 percent decrease in rainfall is predicted for the A2 scenario and an increase of 2 percent for the B2 scenario whereas both the scenarios are predicted for a decrease in rainfall during the first half of the year i.e. January to August and an increase in rainfall from September to November. Change in the rainfall pattern is also persisting. The average annual rainfall of Mumbai is 2504 mm out of which 70% occurs during July to August with 50% occurring in just 2 or 3 extreme events.

Flooding is a common problem due to occurrence of heavy rainfall and related extreme events and high tides of 4-5metrs along with city's 100 years old and clogged drainage system. Over a period of time the frequency and severity of floods are increasing. Climate models predict that the hydrological cycle will be affected with a rise in the intensity of periodic rainfall and following decrease in the number of rainy days (Challinor et al., 2006; Ranger et al., 2011). In July 2005, the city received 944 millimetres of rainfall in a 24-hour time period. Till 1989 the average rainfall of Mumbai was 2129 mm. However, in 2005-2006 the average annual rainfall was 3214 mm (Kumar et al., 2008), an increase of 50% resulting into the most devastating floods leaving more than 500 people dead, mostly in slum settlements. The direct economic damage was estimated more than Rs 50 billion and leaving one million people homeless (Jenamani et al., 2006). The low-income groups and poor residents living in vulnerable and low lying areas (accounting for nearly 50% of Mumbai's population) get affected severely during high rainfall leading to flooding.

2.3. Sea Level Rise (SLR)

The SLR is predicted to be 50 centimetres by 2050 for Mumbai. Mumbai is one of the most vulnerable regions to SLR (GOI, 2012), being financial capital of India, a 1 meter SLR will cost Rs 2,287 billon as estimated by TERI (TERI, 1996). In terms of area submergence, it is also one of the highest affected regions (about 20% of Mumbai's land will be affected). The CMFRI (2011) study reports that about 75 coastal fishing villages of Maharashtra are located within 100 m from the high tide line.The predicted sea level rise along with storm surges will render the coast and low-lying areas where many squatter and fishing communities are located uninhabitable.

2.4. Ecological Degradation and Pollution

The coastal waters are getting polluted due to domestic and industrial wastes which include sewage, chemical wastes and garbage especially plastic wastes are another major challenge. Chemical pollutants are harmful as these cause toxicity. The real estate and infrastructure development at the cost of destruction of mangroves and coastal wetlands are also important reasons for the fall in fish catch (ICOR, 2011). The rivers in Mumbai (Mithi and others) are treated as open drain for discharging hazardous waste to the sea. Kolis, fishing community from Mahim, Bandra, Versova and Worli villages of Mumbai region have reported that the garbage obstructing the water flow into the Arabian sea and also the fishes have gone further into the sea because of this pollution (ICOR, 2011; Salagrama, 2012).

2.5. Financial and Social Burden on Koli Community

Fishery is an important source of livelihood for nearly 41 thousand people in Mumbai. According to the Marine Fishery Census (MFC, 2010), there are 30 fishing villages overcrowding with the increasing number of migrants and urbanisation in Mumbai. There are 612 fishermen families living below poverty line (BPL) (MFC, 2010). Fishing is a seasonal occupation, often during monsoon. Fishermen face hardship due to ban on fishing during bad weather, rise in factors costs, and delay in subsidies etc.

3. MATERIALS AND METHODS

3.1. Objective

The objective of this study is to understand the climatic and associated socio-economic factors and their extent affecting productivity/efficiency of fisheries sector in Mumbai region.

3.2. The Data

Pilot survey, secondary data analysis, and the discussions with various stakeholders (fisherman, government officials, scientist from marine research institute) helped the selection of five fishing villages (Versova, Madh, Khar, Mahim and Worli) in Mumbai region for the present study. The villages were selected on the basis of maximum number of fishing households, fishing as major occupation and number of fishing boats. The pilot survey and in the latter stage, the primary survey was conducted through stratified convenience random sampling method of 200 fishing households from these villages through a structured questionnaire on various social, economic, demographic, physical, health, policy parameters, input-output and data on climate change perception, adaptation measures etc by Sustainable Livelihood Approach (SLA) (Scoones, 1998; Allison and Ellis, 2001). After cleaning the data for outliers, we analyze data of 164 sample size. The survey was conducted over six months starting with the fishing season (mid-August 2011 to February 2012).

3.3 Production Functions and Frontiers in Fisheries

Studies estimating technical efficiency based on econometric techniques are conducted for a wide range of industries, however, relatively few attempts have been made to measure technical efficiency in fisheries. The lack of frontier studies in marine fisheries can largely be attributed to their inherent complexity and consequent difficulty in collecting necessary production data. Furthermore, fishery management authorities are generally more concerned with biological aspects of fishery resources than with economic performance of the fisherman and other aspects like climate change (Sharma and Leung, 1999; Pascoe and Mardle, 2003).

Technical efficiency basically refers to the ability of a firm to produce maximum output given its inputs and available technology. Measurement of efficiency in fisheries is important for several reasons. In spite of being an important source of livelihood for the majority of coastal households, fisheries sector has been facing numerous problems. These include poor and inefficient fishing gears and vessels, lack of capital, poor fisheries management, limited access to better market coupled with poor handling facilities, poor infrastructure and high post-harvest losses (Sesabo and Tol, 2005). Again the lack of alternative employment opportunities and increase in the number of fishing households, are some of the major causes affecting fishing communities. Hence, there is a need to address the interaction of socioeconomic factors and climatic factors affecting fishing households. The objective of an effective fishery management policy is also to improve fish production while, ensuring a sustainable level of fisheries resources, which is the major focus of this study.

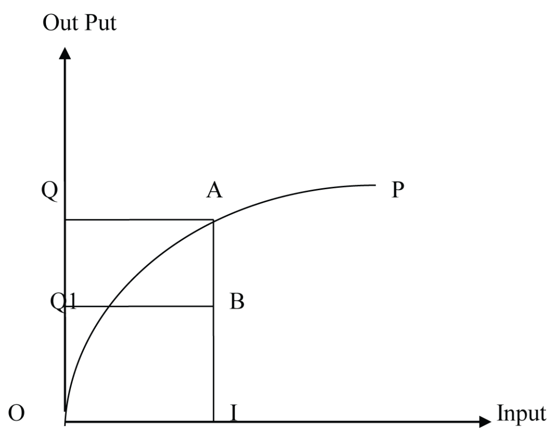
Technical efficiency is a prerequisite for allocative or economic efficiency. Economic efficiency is achieved with the ability to use the inputs at optimal level (highest possible level), given their respective prices. However, while technical efficiency is necessary for economic efficiency, it does not guarantee economic efficiency. The technical inefficiency of an individual firm is measured as a deviation from the benchmark level. The individual firm's output is compared to the frontier level of output given the level of inputs employed, and the resultant difference represents the level of efficiency or inefficiency of the firm. There are four different approaches to measure efficiency. These are (i) the non-parametric programming approach, (ii) the parametric programming approach, (iii) the deterministic statistical approach and (iv) the stochastic frontier production function approach (Aigner et al., 1977; Meeusen and van den Broeck, 1977; Greene, 1980; Kirkley et al., 1995; Greene, 2005). Among these, the stochastic frontier production function and non-parametric programming, known as Data Envelopment Analysis (DEA), are the most popular approaches. DEA imposes less structure on the frontier, but it does not allow for the random errors. The stochastic production frontier approach proposed by Aigner et al., (1977), and later extended by Huang and

Liu (1994) and Battese and Coelli (1995) is the prominent approach for assessing technical efficiency in a commercial fishery (Pascoe and Mardle, 2003).

The stochastic frontier production function represents the existence of technical efficiencies/inefficiencies in the production of firms involved in producing a particular output given the state of technology. Firms operate either on a frontier (they are technically efficient) or beneath the frontier (they are technically inefficient). In the following figure, a simple process of a single input and a single output is presented. The production frontier is OP, the technically efficient firm operates at point A, while the firm operating below the point A, say at B, is a technically inefficient firm. The technical efficiency score for the efficient firm is 1, while for the technically inefficient firm is OQ_1/OQ or BI/AI.

Among all other methods for measuring efficiency, Stochastic Frontier Approach (SFA) is the widely used method for measuring efficiency as it allows the effects of random variation in output to be separated from inefficiency. The model acknowledges the fact that random shocks outside the control of producers can also affect output. The production function of an individual fisherman is stochastic in nature because of the impact of random factors such as weather, resource availability, and environmental influences. Majority of the studies estimate technical efficiency/inefficiency in different types of industries. Too few studies attempt to measure technical efficiency in fisheries and this may be due to difficulty in collecting required production data.

Figure 1. Technical efficiency and inefficiency



Kumbhakar et al., (1991); Reifschneider and Stevenson, (1991); and Battese and Coelli, (1995) have argued that the socio-economic variables may be incorporated directly into the estimation of the production frontier model as such variables may directly influence the production efficiency. We follow the Battese and Coelli, (1995) approach and simultaneously estimate the stochastic frontier production and the inefficiency model in one step using the maximum-likelihood estimation (MLE) program FRONTIER 4.1 (Coelli, 1996).

Considering fishing households denoted by *i*, the general stochastic production function with, inefficiency effects can be defined in the following equation (Pascoe and Mardle, 2003; Sesabo and Tol, 2005).

$$\ln\left(y_i\right) = f\left(\ln xi;\beta\right) + \varepsilon i \quad i = 1,2,3...,n \tag{1}$$

$$\varepsilon i = \nu i - \mu i \tag{2}$$

where yi measures the value of fishing output produced by i^{th} household, xi is a vector of factor inputs and other explanatory variables; β is a vector of unknown scalar parameters to be estimated.

The error term εi here consists of two parts, the term vi is assumed to be independently and identically distributed $N(0, \sigma_v^2)$ error term similar to that in traditional regression model. The term captures random variation in output due to factors beyond control of the fishing households, such as weather, diseases, measurement errors in dependent variables and omitted explanatory variables. The error term ui is a non-negative random variable, associated with technical inefficiency in production frontier. If $ui = 0$, production lies on the stochastic frontier and production is technically efficient; if $ui < 0$, production lies below the frontier and is technically inefficient.

In fisheries production frontier (refer to equation 1), $f(\ln x)$ is known as the deterministic part of the frontier and it generally represented as a function of fishing efforts (capital, capital utilization, and stocks etc.) and stocks abundance. However in some other studies, labour utilisation is included as a measure of the production frontier (Kirkley et al., 1995; Sharma and Leung, 1999). Since production theory considers output as a function of land (i.e. stock), labour and capital. The level of capital employed in the fishery is measured in terms of the monetary investment level (Sesabo and Tol, 2005) or physical inputs such as size of the boat and engine power (Pascoe and Mardle, 2003). Pascoe et al., (2001) estimate capital inputs in monetary terms based on the combination of boat sizes and engine power. Capital utilization can also be incorporated into the analyses in terms of either number of days fished or fuel use. The economic measures (i.e. money terms) of capital is more preferred in the literature rather than the physical measures.

The error term ui is assumed to follow one of the three possible distributions; (i) half normal, (ii) exponential-normal, (iii) truncated normal at zero. We may choose one distributional form over the other as all forms have some advantages and some disadvantages. Most of the above studies of fisheries have adopted the Battese and Coelli (1995) approach, where ui is assumed to be independently and identically distributed and at truncations (at zero) of the normal distribution with mean, μi and variance, $\sigma_u^2 N(\mu i, \sigma_u^2)$, where;

$$\mu i = \delta 0 + Zi\delta + \omega i \tag{3}$$

where Zi is a vector of household specific effects that determine technical inefficiency and δ is a vector of variables which are to be estimated. Household variables which may affect technical efficiency include household size, fishing experience, observations on climate among others. The ωi is a random variable generally defined by the truncation of the normal distribution with zero mean and variance σ^2, with the point of truncation as $\omega i \geq - \delta\ Z i$.

The method of maximum likelihood is used to simultaneously estimate the parameters of the stochastic frontier and technical inefficiency effects model. The likelihood function is expressed in terms of the variance parameters as $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma u^2/(\sigma v^2 + \sigma u^2)$, the value of γ ranges from 0 to 1, with the value equal to 1 indicating that all the deviation from the frontier are entirely due to technical inefficiency (Battese and Coelli, 1995; Coelli et al., 1998).

The technical efficiency of the i^{th} household can be defined as:

$$TEi = E\left[\frac{\exp(-\mu i)}{\nu i - \mu i}\right] \tag{4}$$

where TE is technical efficiency, E is the expectation operator. The above equation shows that the measure of technical efficiency is based on a conditional, given the value of $vi - ui$ evaluated at the maximum likelihood estimates of the parameter in the model, where the expected maximum value of yi is conditional on $ui = 0$ (Battese and Coelli, 1988). The measure TE takes the value between 0 and 1.

Nagothu et al., (2012) in their study explained the differences in efficiencies using socio-economic and climatic variables from shrimp farming in Andhra Pradesh, India. They used a stochastic frontier function and a Cobb-Douglas (CD) production function to study the technical and economic efficiencies of the farmers. However, they followed a two-stage procedure, where in the first stage the specification and estimation of the stochastic frontier production function and the prediction of the technical inefficiency effects are conducted. And in the second stage with the help of a regression model the predicted efficiency scores are expressed as a function of socioeconomic attributes. Economists like, Kumbhakar et al., (1991); Reifschneider and Stevenson, (1991); and Battese and Coelli, (1995) have argued that the socio-economic variables should be incorporated directly into the estimation of the production frontier model because such variables may have a direct influence on production efficiency. Hence, in this study the Battese and Coelli (1995) approach is followed and simultaneously the stochastic frontier production and the inefficiency model are estimated in one step using the maximum-likelihood estimation (MLE) program FRONTIER 4.1 (Coelli, 1996).

Several functional forms are developed to measure the physical relationship between inputs and outputs. Cobb-Douglas and the transcendental logarithmic (translog) functions are the most common forms. We derive these two types of functions for the present study.

Cobb-Douglas production function

$$Ln(yi) = \beta 0 + \sum_{i=1}^{7} \beta i \ln xi + vi - ui \qquad (5)$$

Translog production function

$$Ln\left(yi\right) = \beta 0 + \sum_{j=1}^{7} \beta j \ln xji + \sum_{j=1}^{7} \beta jj (\ln xji)^2 + \sum_{j=1}^{7} \sum_{k=6 j<6}^{7} \beta jk \ln xji \ln xki + vi - ui \qquad (6)$$

where, y = Total revenue earned per trip after selling fish catch (in Rs)

x_1= Number of fishing days, x_2 =Value of boat (in Rs), x_3 = Value of net (in Rs), x_4 = Fuel cost per trip (in Rs), x_5 = Other costs per trip (in Rs), x_6 = Number of fishermen, x_7 = Trip days (in numbers)

The technical inefficiency model is specified as follows.

$$\mu i = \delta 0 + \sum_{i=1}^{10} \delta izi + \omega i \qquad (7)$$

where, z_1= Age (in years)

z_2 = Education (1; illiterate, 2; primary, 3; high school level, 4; higher secondary, 5; graduate and above), z_3= Type of family (1; nuclear family, 2; joint family), z_4 = Training (1, if taken training, 0 otherwise), z_5 = Observation on increase in temperature (1; very high, 2; high, 3; moderate, 4; low, 5; very low), z_6 = Observation on rise in rainfall (1; very high, 2; high, 3; moderate, 4; low, 5; very low), z_7 = Observation on change in rainfall pattern (1; very high, 2; high, 3; moderate, 4; low, 5; very low), z_8 = Observation on sea level rise (1; very high, 2; high, 3; moderate, 4; low, 5;very low), z_9 = Observation on storm level (1; very high, 2; high, 3; moderate, 4; low, 5; very low), z_{10} = Types of electronic gadget used (1; GPS, 2; Satellite, 3; Fish finder, 4; Mobile, 5; other)

The fish catch includes different types of fish and often the exact quantities of these types are not known (as the fishermen sold them in bulk) and different categories of fish have also very different market value. There are three types of boats being used in these villages: Mechanized boats, motorized boats and country boats. Based on their production capacity we have defined mechanized boats owners as large fishermen, motorized boat owners as small and country boats as marginal fishermen. Therefore the total revenue earned per trip from selling fish catch is taken as dependent variable. Costs of fuel and other costs like; ice, storage and transportation costs of shifting fish production to the market, costs of boat and nets, number of working days, number of fishing trips, number of workers etc. are selected as input variable. The age variable is considered as a proxy for fishing experience. Education and awareness on climate change (rise in temperature, change in rainfall pattern and seal level rise) can improve efficiency of fishermen.

4. PRELIMINARY OBSERVATIONS

Fishermen travel extra mile in the sea to get a good catch due to fish migration and sea currents and because of climate change which results in an increase in input use such as fuel, and labour. The mechanized boats usually go for one trip in a week and motorized boats and other boats go for daily trips, however sometimes the fish composition also determine their trip duration during peak season. The mean age of the fishermen is estimated as 43 years and it is found that majority of fishermen belong to the age group of 30-40. Nearly 40% of the fishermen surveyed have studied up to matriculation. Training for fishermen is an important policy measure from government towards improvement of efficiency of fishermen. A proper training can have significant impact on fish production and sustainable adaptation. However it is found that only 22.5% percent of the fishermen surveyed have a formal training on fishing. Few fishermen are better prepared and adapted under changing climate and fisheries practices to improve their fish productivity through the use of GPS, fish finder, and advanced technologies. However these gadgets are unaffordable for many others. If fisherman is not aware of climate change and has a negative perception of the effects on fish production is more prone to adapt strategies to cope up with the climate change (Roy, 2012). It is also revealed that increase in cost particularly fuel and labour affected severely to the fishermen in recent years. Sometimes it forces them to keep their boats stand by and look for alternate livelihood. The fishermen in coastal areas of Mumbai experience climate change events, like, change in rainfall pattern and change in monsoon season, rise in temperature, heavy rain falls, different wind pattern, flood etc. However the observation among fishermen shows that the magnitude of their perception on climate change differs from village to village. 37% of the respondents surveyed, ranked rise in temperature as 'very high', where as 45% as 'high', 11.5% as 'moderate' and only 6.6% ranked it 'low'. Similarly observation on rainfall pattern change is ranked very high by 49%, high by 37%, moderate by 13% and low by a few (0.5%) of the respondents. These perceptions also vary significantly among mechanized and non-mechanized boat owners. Similarly observations on sea level rise and on availability of fish at longer distances are also considered for the current analysis. Fishermen generally believe that reduction in fish catch in the recent years is mainly because of juvenile exploitation, habitat destruction and overfishing. They believed wind direction and speed are two main drivers of fish abundance and availability, followed by rainfall and temperature.

In Table1 the correlation between output and input variables are derived and presented. The correlation results show that most of the variables are highly correlated with each other and also with the output variable.

5. RESULTS

5.1. Maximum Likelihood Estimates

The OLS as well as maximum likelihood estimates for the parameters in the equation (5), (6) and (7) (for CD as well as translog functions) are presented in the following tables. The estimate of gamma (γ) is 0.8 and significant in the CD model and shows that the vast majority of the error variation is due to the inefficiency error μi and not due to the random error vi. This indicates that the random component of the inefficiency effects does make a significant contribution in the analysis. The one sided LR test of γ=0 provides

Table 1. Correlation between output variable and input variables

	Ttl. Rvn	Work. Days	Value Boat	Value. Nets	Fuel Costs	Oth_ Cost	No. of People	Trip. Week	Age	Edn	Type. Faml	Training	Obs. Temp	Obs. Rainfall	Obs. Rainfall Pattern	Obs. Sea Level Rise	Obs. Storm Level	Elec. Gadgets
Ttl. Rvn	1.000																	
Work. days	-0.205**	1.000																
Value boat	0.747**	-0.112	1.000															
Value. nets	0.397**	-0.043	0.442**	1.000														
Fuel Costs	0.857**	-0.204**	0.796**	0.461**	1.000													
Oth. cost	0.725**	-0.186*	0.754**	0.470**	0.870**	1.000												
No. of people	0.654**	-0.148	0.691**	0.470**	0.671**	0.529**	1.000											
Trip. week	-0.676**	0.437**	-0.608**	-0.419**	-0.658**	-0.573**	-0.555**	1.000										
Age	0.049	-0.164*	0.014	0.265**	0.084	0.077	0.068	-0.234**	1.000									
Edn	0.148	0.006	0.134	0.074	0.070	-0.011	0.291**	-0.070	-0.172*	1.000								
Type. faml	-0.101	0.035	-0.008	0.229**	-0.025	0.075	0.008	0.094	0.058	0.054	1.000							
Training	-0.035	0.069	-0.208**	-0.215**	-0.073	-0.128	-0.129	0.150	-0.162*	-0.108	-0.108	1.000						
Obs. temp	-0.211**	-0.074	-0.203**	-0.191*	-0.114	-0.130	-0.189*	0.033	0.017	-0.080	-0.089	-0.023	1.000					
Obs .rainfall	0.416**	-0.135	0.220**	0.153	0.286**	0.141	0.255**	-0.352**	0.023	0.183*	-0.203**	0.084	0.020	1.000				
Obs. rainfall pattern	0.168*	0.028	0.187*	0.047	0.146	0.150	0.064	-0.073	-0.023	0.029	0.027	-0.039	0.085	0.138	1.000			
Obs. Sea level rise	0.141	0.008	0.147	0.159*	0.129	0.190*	0.042	-0.062	0.057	0.046	0.034	-0.004	-0.110	0.003	0.146	1.000		
Obs. storm level	0.248**	-0.028	0.179*	0.264**	0.286**	0.273**	0.184*	-0.179*	0.169*	0.013	-0.065	-0.049	0.003	0.119	0.143	0.261**	1.000	
Elec. gadgets	-0.804**	0.188*	-0.550**	-0.348**	-0.727**	-0.575**	-0.592**	0.638**	-0.108	-0.079	0.183*	0.008	0.187*	-0.342**	-0.054	-0.113	-0.275**	1.000

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

a statistic of 39.8 which exceeds the chi-square five per cent critical value of 15.51. Hence the stochastic frontier model does appear to be a significant improvement over an average (OLS) production function. Only three variables out of seven variables selected for the study are found as significant (Table 2). These are number of working days, fuel costs and the number of trips. However the increment in number of working days will increase .3 percent of the output, similarly increase in fuel costs will increase 0.43 percent of output on the other hand increase in number of trips will affect .17 percent of output negatively. During the field survey it was also revealed that increase in fuel costs affecting fishermen severely. Fishermen now wants to make less number of trip however, wants to catch maximum fish in order to minimize their costs. In the CD function the mean technical efficiency is derived as 30.62 percent (Table 3), which is very low. Only 24 fishermen have efficiency of more than 50%. This reflects there is a scope to increase efficiency for many fishermen and to meet the highest efficiency level. Given the efficiency estimated for each fishing household using CD function, now one can easily identify the determinants of this efficiency level or we can analyse why some fishing households are more efficient than others. A negative sign on a parameter that is explaining inefficiencies means that the variables improve technical efficiency, while the reverse is true for a positive sign. Table 4 shows only three parameters significantly explaining the efficiency in the CD function. These are type of family (with a negative sign), observation on temperature change and electronic gadgets used in fishing (Sesabo and Tol, 2005; Basnayake and Gunaratne, 2002). The fishermen belonging to nuclear family are more efficient or the inefficiency increases with the increase in family size.

Table 2. OLS estimates and maximum likelihood estimates for parameters of the stochastic frontier (Cobb-Douglas model)

		Coefficient		t-Ratio	
Variable	**Parameters**	**OLS**	**MLE**	**OLS**	**MLE**
Constant	β0	1.15	3.89	1.2	3.12*
Number of Working days	β1	0.39	0.3	1.82***	1.74***
Value of boat	β2	0.16	0.13	1.9**	1.56
Value of nets	β3	0.003	0.05	0.03	0.54
Fuel Costs	β4	0.53	0.43	10.73*	7.47*
Other costs	β5	0.08	0.05	1.71***	0.92
Number of workers	β6	0.25	0.21	1.7***	1.41
Number of trip days	β7	-0.23	-0.17	2.51**	-2.01**
Sigma squared ($\sigma^2 = \sigma_v^2 + \sigma_u^2$)			0.27		7.68*
gamma $\gamma = \sigma u^2/(\sigma v^2 + \sigma u^2)$			0.8		3.22*
Log-Likelihood		-141.35	-121.45		
LR test			39.8		

*=1% significance level, **=5% significance level, ***=10% significance level

The observation on temperature change implies fishermen observing higher temperature change are more efficient (only because they adapt to the situation very well). Similarly fishermen using advanced electronic gadgets are more efficient than others.

5.2. Translog Function Results

A stochastic translog production frontier was estimated as a test of robustness in the choice of functional form. The form of this model encompasses the Cobb-Douglas form, so test of preference for one form over the other can be undertaken by analyzing significance of cross terms in the translog form (Basnayake and Gunaratne, 2002). The number of parameters affecting output in the translog model is more in comparison to the earlier model of CD function (Table 5). Except number of trip all other variable are significant. The coefficient value for number of working days is highest showing increase in number of working days the increase is output will be more. Value of nets, value of boats and fuel costs affect the output positively on the other hand, other costs, and number of workers affect negatively to the output. The gamma estimates for the function ($\gamma = 0.90$) also higher and this suggests that technical inefficiency effects are significant components of total variability of fishing output for the sample of households (Battese and Coelli, 1995).

Technical efficiency estimates obtained by Cobb-Douglas and translog models differ very much. The mean technical efficiency score in translog model is 40, and 46 fishermen having efficiency score more than 50 (Table 6). More discussion on the efficiency is presented in the next section.

Like the efficiency model discussed for CD function, in case of translog model it was also derived and presented in the following table (Table 7). The table shows similar results, only three variables education, observation on temperature change, and electronic gadgets used are found as significant. Whereas the parameter value for education is having a negative sign this suggests that the educated farmers are more efficient than others.

Table 3. Distribution of technical efficiencies (based on Cobb-Douglas specification)

Technical Efficiency (%)	Frequency	Percentage	Mean Efficiency (%)
Less than 20	64	39.02	14.95
21-30	36	21.95	25.61
31-40	25	15.24	35.56
41-50	15	9.15	45.33
51-60	7	4.27	54.00
61-70	11	6.71	65.45
Greater than 70	6	3.66	79.33
	164		Mean Efficiency of the 164 households is 30.62

Table 4. Determinants of inefficiency-Cobb-Douglas Model

Variable	Parameter	Coefficient	t-Ration
Constant	$\delta0$	0.7503	1.47
Age	$\delta1$	-0.0008	-0.17
Education	$\delta2$	-0.08	-1.4
Type of family	$\delta3$	-0.2364	-2.21**
Training	$\delta4$	0.0813	0.71
Obs. Temperature	$\delta5$	0.1739	2.91*
Obs. Rainfall	$\delta6$	-0.027	-0.5
Obs. Rainfall pattern	$\delta7$	-0.0729	-1.01
Obs. Sea level	$\delta8$	-0.0217	-0.41
Obs. Storm	$\delta9$	0.0167	0.29
Electronics. Gadgets	$\delta10$	0.24	3.38*

*=1% significance level, **=5% significance level, ***=10% significance level

Table 5. Maximum likelihood estimates for parameters of the stochastic frontier (translog)

Variables	Parameters	Co-Efficient	t-Ratio
Constant	β0	-68.09	-68.42*
No. of Working days	β1	17.36	17.54*
Value of boat	β2	1.9	2.43**
Value of nets	β3	6.9	8.56*
Fuel costs	β4	2	2.3**
Other costs	β5	-2.23	-2.37**
No. of workers	β6	-4.6	-4.56*
No. of trip days	β7	-0.5	0.51
No. of Working days x No. of Working days	β1 x β1	-0.05	-0.15
Value of boat x Value of boat	β2 x β2	-0.18	-1.77***
Value of nets x Value of nets	β3 x β3	-0.25	-2.86*
Fuel costs x Fuel costs	β4 x β4	-0.01	-0.38
Other costs x Other costs	β5 x β5	-0.07	-1.94***
No. of workers x No. of workers	β6 x β6	-0.02	-0.06
No. of trip days x No. of trip days	β7 x β7	-0.43	-2.35**
No. of Working days x Value of boat	β1 x β2	-0.3	-0.78
No. of Working days x value of nets	β1 x β3	-1.17	-2.91*
No. of Working days x Fuel costs	β1 x β4	-0.04	-0.14
No. of Working days x Other costs	β1 x β5	-0.08	-0.4
No. of Working days x No. of workers	β1 x β6	1.37	1.78***
No. of Working days x No. of trip days	β1 x β7	-0.31	-0.62
Value of boat x value of nets	β2 x β3	0.19	1.43
value of boat x Fuel costs	β2 x β4	0.14	1.64***
Value of boat x Other costs	β2 x β5	0	0
Value of boat x No. of workers	β2 x β6	0.19	0.55
Value of boat x No. of trip days	β2 x β7	0.18	1.19
Value of nets x Fuel costs	β3 x β4	-0.23	-2.75*
Value of nets x Other costs	β3 x β5	0.28	2.76*
Value of nets x No. of workers	β3 x β6	0.05	0.2
Value of nets x No. of trip days	β3 x β7	-0.02	-0.16
Fuel costs x Other costs	β4 x β5	0.03	0.7

continued on following page

Table 5. Continued

Variables	Parameters	Co-Efficient	t-Ratio
Fuel costs x No. of workers	β4 x β6	-0.22	-2.0**
Fuel costs x No. of trip days	β4 x β7	-0.21	-1.93**
Other costs x No. of workers	β5 x β6	-0.14	-0.76
Other costs x No. of trip days	β5 x β7	0.11	1.31
No. of workers x No. of trip days	β6 x β7	-0.11	-0.42
Sigma squared ($\sigma^2 = \sigma_v^2 + \sigma_u^2$)		0.25	9.53*
gamma $\gamma = \sigma u^2/(\sigma v^2 + \sigma u^2)$		0.90	14.56*
Log-Likelihood		-96.62	

*=1% significance level, **=5% significance level, ***=10% significance level

5.3. Technical Efficiencies

The estimated mean efficiency level for the fishing household is derived as 0.40 (40%) (Table 6). Though the distribution of efficiencies varies among fishing households, the mean efficiency shows most of the household having a very low level of efficiency which further provides scope for improving efficiency and thus profits. The low level efficiency is not only a major concern for the fishermen alone but also for the policy makers and the government. The following Table 3 presents frequency distribution of household level efficiency scores. Only 15% of the fishing households have efficiency of more than 70%, whereas nearly 23% households having efficiency in between 21-30%.

Village level mean efficiency scores are presented in the following (Table 8). The mean efficiency score for Versova is 53.62 followed by Mahim 43.1. Most of the fishermen surveyed from these two villages having mechanized boats, whereas fishermen from Worli and Khar are less efficient with mean efficiency level of 26.65 and 25.2. The mean efficiency of fishermen in Madh is 40.64. Fishermen in these villages own more of motorized and country boats. The type of boat is an important factor which decides not only the

Table 6. Distribution of Technical Efficiency from translog model

Technical Efficiency (%)	Frequency	Percentage	Mean Efficiency (%)
less than 20	36	22.00	15.08
21-30	37	22.60	25.91
31-40	28	17.10	34.64
41-50	17	10.40	45.00
51-60	10	6.10	56.50
61-70	11	6.70	64.90
Above 70	25	15.20	84.60
	164		Mean Efficiency of the 164 households is 40

Table 7. Results of the Inefficiency model for translog function

Variables	Parameters	Co-Efficient	t-Ratio
Constant	δ0	0.24	0.6
Age	δ1	0	0.44
Education	δ2	-0.09	-1.62***
Type of family	δ3	-0.16	-1.46
Training	δ4	-0.05	-0.4
Obs. Temperature	δ5	0.15	2.53**
Obs. Rainfall	δ6	-0.01	-0.19
Obs. Rainfall pattern	δ7	-0.11	-1.4
Obs. Sea level	δ8	-0.04	-0.67
Obs. Storm	δ9	0	-0.08
Electronics. Gadgets	δ10	0.3	5.27*

*=1% significance level, **=5% significance level, ***=10% significance level

economic wellbeing of the fishermen but also the scale of operation, efficiency and technology used.

Further, Table 9 shows that out of 53 large scale fishermen owning mechanized boats, 25 fishermen score efficiency level of more than 60. On the other hand 29 small scale fishermen owning motorized boats score efficiency level of

Table 8. Village level efficiency scores

Village	Observation	Percent	Mean Efficiency
Khardanda	34	20.73	25.2
Madh	28	17.07	40.64
Mahim	28	17.07	43.1
Versova	54	32.92	53.62
Worli	20	12.19	26.65
Average mean efficiency of all observation=40			

less than 20, and 28 score in between 21 and 30. Country boat marginal fishermen do not exceed 40 level of efficiency. For operating country boats, fisherman needs one additional fisherman/labourer. Fishermen who own country boat, have started using petrol engine to fishing the deep sea and still find it difficult to find fish as a result of declining fish in waters. In order to balance the incomes and reduce risk, some fishermen operate with more than one boat to cross-subsidize the losses. In the case of trawl fisheries, the crew members including wage earners share total fish catch or income. Also fish catch operation is carried out jointly by fifteen to twenty boats owners for safety and exchange of information purposes.

Table 9. Efficiency scores and types of boats

	Large Scale Fishermen Owning Mechanized Boats	Small Scale Fishermen Owning Motorized Boat	Marginal Scale Fishermen Owning Country Boat	Total
less than 20	0	29 (30.2%)	7 (46.7%)	36 (22%)
21-30	5 (9.4%)	28 (29.2%)	4 (26.7%)	37 (22.6%)
31-40	6 (11.3%)	18 (18.8%)	4 (26.7%)	28 (17.1%)
41-50	8 (15.1%)	9 (9.4%)	0	17 (10.4%)
51-60	9 (17.0%)	1 (1%)	0	10 (6.1%)
61-70	9 (17.0%)	2 (2.1%)	0	11 (6.7%)
Above 70	16 (30.2%)	9 (9.4%)	0	25 (15.2%)
Total	53 (32.3%)	96 (58.5%)	15 (9.1%)	164 (100%)
Mean efficiency	59.64	32.65	22.33	

(Percentage of households are in bracket)

Rise in input cost such as labour, cold storage and also competition from the migrants making small and marginal fishermen inefficient compared to large fishermen with mechanized boats. Also fishermen having membership of the cooperative society improves their technical and economic efficiencies better than others due to the interaction and information dissemination (Nagothu et al., 2012).

Also electronic gadgets like; GPS. Satellite phone, fish finder and the uses of mobile have significantly affected the efficiency level of fishermen (Table 10) (Salagrama, 2012). 35.3% of the GPS users score efficiency more than 70. Similarly 32.4% of the satellite phone users score efficiency more than 70. Whereas the uses of mobile phone has not been found much effective towards improving efficiency scores of fishermen. The other gadgets like radio, TV are also not found as efficient. Although the government provides subsidies for the purchase of electronic gadgets like GPS and satellite phone, they are still beyond means of small and marginal scale fishermen. The results suggest that large fishermen owning mechanized fishing boats and electronic equipment are much more efficient in catching fish as compared to small and marginal fishermen.

6. CONCLUSION AND POLICY IMPLICATIONS

We attempt to understand the climatic and socio-economic factors influencing the fish productivity and the livelihood of fishing community in Mumbai. We find efficiencies and the factors affecting efficiencies of fish production process in five villages of Mumbai region by using stochastic frontier function and a Cobb-Douglas production function. The study derives some interesting conclusions. Fuel costs, number of working days, no of trips and number of workers are the most important variables significantly affecting the fish production. Large scale fishermen owning mechanized boats are found most efficient (nearly 60% mean efficiency) in fish production as compared to small (nearly 22% mean efficiency) and marginal fishermen (nearly 38% mean efficiency). The use of electronic gadgets found to improve the efficiency level of fishermen significantly. While other gadgets like television and radio are not found as efficient. Among the inefficiency parameter, observation on temperature change and electronic gadgets used, type of family and education level of the fishermen have significant effect on productivity. Fishermen are now observing a

Table 10. Efficiency scores and electronic gadgets used

Technical Efficiency (%)	GPS	Satellite Phone	Mobile	Others	Total
less than 20	0	0	19 (29.7%)	17 (37.0%)	36 (22%)
21-30	0	5 (13.5%)	15 (23.4%)	17 (37%)	37 (22.6%)
31-40	1 (5.9%)	5 (13.5%)	15 (23.4%)	7 (15.2%)	28 (17.1%)
41-50	5 (29.4%)	6 (16.2%)	5 (7.8%)	1 (2.2%)	17 (10.4%)
51-60	2 (11.8%)	4 (10.8%)	3 (4.7%)	1 (2.2%)	10 (10.4%)
61-70	3 (17.6%)	5 (13.5%)	3 (4.7%)	0	11 (6.7%)
Above 70	6 (35.3%)	12 (32.4%)	4 (6.2%)	3 (6.5%)	25 (15.2%)
Total	17	37	64	46	164

(Percentage of households are in bracket) different climate pattern; accordingly they adapt and target those fish species available in winter and summer season. As per these results, there is need to improve the scale of operation of small and marginal fishermen operating with motorized and country boats and also to improve their adaptation capabilities. Since fuel subsidies lead to market and environmental distortions, adequate and timely direct transfer of benefits to small and marginal fishermen is suggested for timely and improved fishing operations. Electronic gadgets such as television and radio are not found as efficient which reflects that mass communication system has not been harnessed to provide climate change and adaptation awareness and storm, cyclone, heavy rainfall alerts to the fishermen. This intensive and indiscriminate trawling in the coastal waters along with the intention of catching even juvenile and baby fish may be regulated and controlled (ICOR, 2011). In the event of draught, farmers are compensated whereas in the similar event "no fish catch", fishermen are not compensated. There is a need to insure them by diversifying and providing alternative employment opportunities.

6.1. Future Scope

This study can further be extended by including other fishing villages of Mumbai in the analysis. A comparative study of fishing villages in Mumbai and fishing villages from other regions like Odisha coast where fishermen are comparatively poor and more vulnerable to climate change, can be conducted. Though the production function included both CD and translog function, other models like bio-economic model can be used for future analysis.

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Chapter 13
Bioeconomic Fishery Management:
Changing Paradigms towards Eco-System Based Management

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ABSTRACT

Coastal areas are also important ecologically, as they provide a number of environmental goods and services. Potentially, if managed sustainably, they can provide continuing returns without any decrease in their productivity. But, the unfolding state of coastal ecosystems, from the standpoint of fisheries production, is causing concern. A move towards fishing management that conserves biodiversity, permits sustainable utilization and recognizes the importance of species interaction is worthwhile. Recent recognition of such interactions in fishing has resulted in calls for adoption of ecosystem approaches to fishery management to rebuild and sustain populations, species and biological communities at high levels of productivity and biological diversity. The coupling of fishery management issues more directly with the issues of marine pollution, and biodiversity represents an increasing understanding of the linkages among them. This calls for changing fishery management paradigms towards a more coherent ecosystem approach.

1. COASTAL ECOSYSTEM AND FISHERY LINKAGES: THE GLOBAL SCENARIO

Ecosystems are complex, linked, interactive systems in which organisms, habitats and external forces (e.g., ocean currents, weather) act together to shape communities and regulate population abundances. Humans are components of the ecosystems they inhabit and use. Their actions on land and in the oceans measurably affect ecosystems, and changes in ecosystems affect humans[11].

Coastal area[2] is commonly defined as the interface or transition area between land and sea. The potential for economic opportunities in coastal cities is a strong attractive force, fuelling immigration, often from economically depressed rural areas. Thus, coastal areas are extremely

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important for the social and economic welfare of current and future generations, as coastal resources support key economic and subsistence activities. Coastal areas are also important ecologically, as they provide a number of environmental goods and services. Marine and estuarine areas often benefit from flow of nutrients from the land and also from ocean upwelling that brings up nutrient-rich water to the surface. They thus tend to have particularly high biological productivity and also support a rich biological diversity. Five main zones can be identified in the coastal-marine spectrum: *inland areas*, which affect the oceans mainly via rivers and non-point sources of pollution; *coastal water*, generally estuaries where the effects of land-based activities are dominant; *coastal lands*, where human activity is concentrated and directly affects adjacent waters; *offshore waters,* mainly out to the edge of national jurisdiction (200 nautical-miles offshore) and *high seas*, beyond the limit of national jurisdiction. The ecosystem has tremendous pressure from its varied uses. The major activities in the ecosystem include fisheries and tourism. With multifarious use there is bound to be conflict among the different users.

Coastal ecosystems (including marine fisheries) cover approximately 22% of the total land area in a 100-km band along continental and island coastlines; as well as the ocean area above the continental shelf. According to the 1994 distribution of population in relation to the distance from the nearest coastline, 20.6% of the world's population lives within 30 km of the coast, and 37% within 100 km (Gommes, 1997). About one-half of the world's population lives within 100 km of the coast, the part of the sea most accessible to man.The coastal zone is home to roughly 2.2 billion people or 39% of the world's population and yields as much as 95% of the marine fish catch (World Resources 2000-2001, 2002). Marine fish generates around 1% of the visible global economy and supports the livelihoods of some 200 million people. Fisheries are a large international business. They also provide direct and indirect employment for about 200 million people (Garcia and Newton, 1997). Marine capture fisheries usually yield near about 84 million metric tons of fish and are by far the largest contributor to the 14 kg of fish available as food per person (FAO, 1997). Out of these global fishery products, approximately 28% are used for animal feed and other products that do not contribute directly to human food. So its importance in terms of providing nutritious food cannot be denied. This is especially true for developing countries.

Fisheries development is essential, both as a means of increasing levels of food production and as a means of improving the quality of diet in developing countries. As a source of protein, vitamins and essential minerals, fish provides an ideal supplement to the poor and monotonous diet which is the daily fare of the inhabitants of many tropical and sub-tropical countries (Bailey, 1988). Indeed, the natural resources of the sea are extremely valuable and renewable. Potentially, if managed sustainably, they can provide continuing returns without any decrease in their productivity.

But, the unfolding state of coastal ecosystems, from the standpoint of fisheries production, is causing concern. Many marine fisheries are in decline and globally it has reached a plateau of about 84 million metric tons. Reported landings have leveled off at approximately 85 million tons since 1989. An evaluation of the global status of fishery resource species in 1994 has listed 31% as lightly to moderately exploited, 44% as fully to intensively exploited, 16% as overexploited, 6% as depleted and 3% as recovering (Garcia and Newton, 1997). Yields of 35% of the most important commercial fish stocks have declined between 1950 and 1994 (Grainger and Garcia, 1996)[33]. Estimates of the production capacity of the oceans give limits to catch at 100-200 million ton. General patterns are of declining yields for 35% of all species, with 25% showing relatively stable yields at high exploitation levels, and 40% with some development potential (FAO, 1997). Therefore the recent global trends suggest that we are near or have exceeded the limits to overall yield from coastal areas of the world. The global marine fish catch is approaching its upper limit. The number of overfished population indicates that management[44] has not succeeded in achieving a principal goal- sustainability.

Climate change is already having a profound effect on life in the oceans. Marine species tend to be highly mobile, and many are moving quickly toward the poles to stay cool as average ocean temperatures rise. These shifts can cause ecological disruptions as predators become separated from their prey. They can also cause economic disruptions if a fish population becomes less productive or moves out of range of the fishermen who catch them.In addition to getting warmer, the oceans are also becoming more acidic as they absorb about one-half of the CO2 we emit into the atmosphere. This increased acidity can make life difficult for organisms that build shells out of calcium carbonate. This includes not only corals and shellfish, but also tiny organisms like pteropods that form the foundation of many marine food webs.

This has enormous implications for developing countries, where fish are a particularly important part of the diet and subsistence fishers still make up a sizeable portion of the populace. Here the potential human costs of the current decline in fisheries are even greater. The prices of most fish species continue to rise as harvests shrink, making fish a less affordable meal among low-income populations. Meanwhile, continued overfishing of near-coastal waters by subsistence and other small-scale fishers, aggravated by competition with larger mechanized fishing vessels, leads to a cycle of smaller catches and increasing damage to the resource base. Successful marine fisheries conservation measures are necessary not only to allow a larger global catch but also to keep fish diversity high, to reduce impacts on marine ecosystems, and, ultimately, to maximize sustainable employment in the fisheries sector (FAO, 1995). It is expected that a more holistic approach incorporating interspecific interactions and environmental influences would contribute to greater sustainability (Botsford et al., 1997).

Coastal ecosystems that are most susceptible and are at risk from pollution, particularly from those that are long-term and chronic in nature, are the estuaries as well as adjacent waters that support important fisheries. The value in terms of economic yield of these natural biological resources to the region alone is of high importance and thus there is an urgent need to assess its development. The need for improved management stems from the fact that continued deterioration of coastal ecosystems and the probable fish stocks that they can support may have serious implications for future fish consumption. The fish in the oceans and estuaries are of considerable importance to the well-being of humans in the form of nutritious, diverse and delicious food. FAO expects that the demand for fish as a human food source to continue to increase well beyond today's consumption of 93 million tons per year. This is alarming in a time when world population is projected to double by 2030, and the UN Food and Agricultural Organization reports that most traditional marine fish stocks have already reached full exploitation (Brown, 1993). FAO warns that only under the most optimistic scenario, where overfishing is brought under control so that fish stocks can recover, will there be enough fish to meet global demand (FAO, 1999). But if the present rate of deterioration continues a substantial gap between supply and demand is likely to develop, raising the price of fish and threatening food security in some regions (Williams, 1996). The current pattern of use, if continued, will lead to decline in the ability of ecosystems to yield their broad spectrum of benefits. This requires reorientation of our outlook of the ecosystem.[512].

Fisheries and coastal ecosystem interact. Recently, as the potential and actual adverse effects of human fishing activities have become apparent, views regarding marine ecosystems are changing. So long, the sea was considered to be inexhaustible in its supply of protein for human use. But it is no longer so[613]. FAO (1999) has reported that 75% of all fish stocks for which information is available are in urgent need of better management- 28% are either already depleted from past overfishing or in imminent danger of depletion due to current overharvesting, and 47% are being fished at their biological limit and therefore vulnerable to depletion if fishing intensity increases (Garcia and DeLeiva Moreno, 2000). The productivity of ecosystems is being lost through poor management and becomes difficult and costly to replace. It is only well-managed ecosystems that can provide a range of benefits over the long term. Global climate change in the marine environment that are occurring include rising sea levels [in most areas], warming water temperatures, increasing acidification and differences in patterns of precipitation all of which can impact productivity and structure of marine ecosystems. Concomitantly "global changes are taking place in human systems which impact the oceans, including changing lifestyles, intensive fishing, the globalization of trade and, as food prices continue to rise, the need to feed the world's population" (Perry and Ommer, 2010).

2. TRADITIONAL FISHERY MANAGEMENT PRACTICES

A fundamental premise of fishery management is that the productive potential of a stock of a fishery depends on the abundance and biomass of the fish present in the stock. Most fishery-management programs depend on assessments of the stock and its productive potential (National Research Council, 1995). In such cases the main problem that arises is that of locating the resource, estimating their abundance and response to exploitation and consequently designing of harvesting measures to ensure an optimum and sustainable yield.

At a point of time, fishery science felt that fish stocks should be harvested to provide a maximum sustainable yield. Subsequently, it was suggested that fisheries should be managed to maximize net economic return. Yield maximization dominated interest during the first half of the twentieth century[713]. At that time, the objective of fishery management was to maintain the maximum biologically sustainable yield from a fishery, with limited concern for social, economic and environmental factors. It is now generally recognized that biological and economic factors require consideration in the development of management objectives (Leavastu, 1996). It is the inability of fisheries management[814] to adapt to and preserve the diversity of the exploited ecosystems which can be earmarked as probably one of the major factors causing depletion of fish stocks (Hammer et al., 1993).

The need for better marine fishery management has become abundantly clear over the past decade (FAO, 1995; Weber and Gradwohl, 1995). No fishery development is advisable without recognition of the limits of sustainability within the fishery. This is essentially why in the past marine fishery management has not been fully effective. Marine fisheries have largely been managed for the growth and development of their associated commercial fishing industries. Decision makers have paid scant attention to the sustainability of those fisheries much less the health of their associated ecosystems. So the key fisheries management problem to be addressed is just not the preservation and production of a particular fish species that has been so long targeted and exploited and is therefore threatened by extinction, but rather the maintenance of the resilience and ecological functions of those ecosystems on which food production depends (Barbier et al, 1994).

Fishery policy failures in the past were not anticipated because the biological indicators used to assess the policy was poorly understood. There must be a shift of the proper focus of fishery management indicators from development and exploitation objectives to conservation and sustainability objectives[915]. Management of marine ecosystems centers around obtaining optimum yields from fish and sustaining these yields over time. Connected to this objective is the maintenance of marine ecosystems in such a state that the biological production of the desired species is sustained. So the management objectives are essentially economic, guided and restrained by biological-ecological conditions in the ecosystems. Table 1 lists some emerging objectives of fishery management along with its indicators. Management must intend to maximize some specified biological or economic benefits from fishery while minimizing costs.

Another important facet to traditional management of fisheries is its aim to optimize the catch of certain economically important species by commercial fishing boats. But this goal often eventually results in the collapse of the targeted species itself. This realization has called for broadening the focus of such management exercises and including a multi-dimensional view emphasizing on ecological and economic sustainability of the fishery system (Charles, 1994). Herein also lies the reason for management to shift from its traditional focus of maximizing the yield of individual resources towards broader considerations of other impacts of fishing on ecosystem as a whole. Here, the consequences of making errors of two types (Type I and Type II) when testing the null hypothesis of no effect are clearly determined and stated. Ignoring the type II error results in failure to recognize and avoid long-term damage such as the collapse of fisheries. The environmental consequences from type II errors are much more serious because of the great time lags in the recovery of the ecosystem while type I errors result only in short-term economic costs (Dayton, 1998). If society's environmental needs are to be protected so that future generations can also profit from marine ecosystems, management must be so adapted that those hoping to exploit them must demonstrate no ecologically significant long-term changes (Wilkinson, 1979).

Table 1. Objectives of fishery management and its indicators

Objectives†	Biological	Economic	Social	Political	Indicator‡
Protect habitat	*				Proportion of habitat impacted by fishing gear
Rebuilt overexploited stocks	*				Abundance of overexploited species
Maximise protein supply	*		*		Weight of landings
Maximise income		*			Total income from fishery
Maximise profit		*			Total profit from fishery
Maximise employment			*		Number of people working in a fishery
Keep prices low		*			Price of fished species
Minimise variability in catch			*	*	Variation of yield per unit time
Minimise variability in income		*	*		Variation of income per unit time
Reduce overcapacity			*		Numbers of fishers or vessels in fishery
Raise government revenue		*	*	*	Value of taxes collected from fishers
Improve catch quality		*			Price paid per unit weight of catch
Increase exports		*			Value and volume of exports
Reduce conflicts				*	Number of prosecutors for conflicts
Increase selectivity	*				Proportion of habitat target species in total catch
Prevent mortality of rare species	*				Mortality rate and abundance of rare species

†based on Clark (1985)
‡based on Hilborn and Walters (1992)

The effects of climate change on commercial fisheries are only beginning to be understood, yet fishery managers have a responsibility to prepare for and respond to changing conditions. At a national level, managers are trying to develop a strategy to incorporate climate change into management of ocean and coastal areas. Although knowledge of potential changes to fishing patterns and effects on ecosystem dynamics may be imperfect, there remains scope for managers to be proactive. Proactive and precautionary management actions in light of uncertainty about the ecosystem effects of warming trends and potential expansion of fishing activities to best utilize, conserve, and protect world's fisheries resources. The measures of fishery management actions as fishery managers and policy-makers operate under a shifting climate and seeking a balance between various management objectives. These are steps that can be taken to be risk averse in preparation for climate change and resulting shifts in fishing patterns.

3. ECOSYSTEM-BASED APPROACH TO FISHERIES

Maximum potential global marine fisheries yield has been estimated, among others, by Schaefer (1965) as 200 million tons, Ryther (1969) as 100 million tons, Idyll (1973) as 400-600 million tons, Houde and Rutherford (1993) as more than 300 million tons. Based on these estimates, one might conclude that we have not yet reached maximum global fisheries yield. However, these estimates were made using unrealistic assumptions about food-web structure (Pauly, 1994) and feedback effects of fishing on other fish populations and marine ecosystems. The estimates were primarily based on single-species considerations. However, anthropogenic impacts, which include contamination with toxic elements, continue to occur and are important. The focus has, therefore, broadened[1016].

A move towards fishing management that conserves biodiversity, permits sustainable utilization and recognizes the importance of species interaction is worthwhile. Recent recognition of such interactions in fishing has resulted in calls for adoption of ecosystem approaches to fishery management to rebuild and sustain populations, species and biological communities at high levels of productivity and biological diversity. Decision-makers in fisheries management are confronted with the challenge of how to respond to existing and predicted changes in ocean conditions that are likely to affect the stocks of fish they manage. In order to address climate change most research and thinking advises decision-makers to ensure that fisheries are well-managed and abundant in an ecosystem context. These policies can best allow fisheries to adapt to changing climate. To address climate change, decision-makers should carefully monitor changing conditions and potential changes in factors affecting fish stock abundance. An adaptive approach to fisheries management under conditions of climate change requires that decision-makers engage with fishing interests in a transparent manner and in ways that respect the input of fishing interests and in ways that acknowledge the levels of uncertainty. This approach implies a governance approach to management that is closer to co-management or shared management responsibility than in most hierarchical processes that characterize fishery management to date. The answer to the question of when fishery decision-makers should begin to incorporate climate change into decision making processes is that they should have started yesterday. The justification for this is that even today, climate variability can affect fishery management decisions and the sooner this is understood and incorporated into the management process the better. In economic terms, a conservative decision relative to fisheries management is likely to produce a positive long term benefit whereas the failure to recognize the need to act in time may have serious immediate negative consequences especially when compounded by inadequate management. While climate change can also produce positive consequences for some species a note of caution is still advised in anticipating and responding to such opportunities.

The general theme in the reinvention of fisheries management is ecological management or ecosystem-based management (Larkin, 1996). Ecosystem-based fishery management can be defined as "a strategy to regulate human activity towards maintaining long-term system sustainability" (Langton et al, 1996). It means that it is a fishery in its entirety that is managed, not just one species, because most species have significant ecosystem interactions. Such approaches based on maintaining healthy ecosystems provide realistic prospects for sustaining fisheries in variable environments, as well as protection of biodiversity. An ecosystem approach to fishery management addresses human activities and environmental factors that affect an ecosystem, the response of the ecosystem and the outcomes in terms of benefits and impacts on humans. The traditional view of a fishery narrowly fits into this framework with fishing as the only stress, the ecosystem response specified solely in terms of the effect of fishing mortality on a single species, and the outcome in terms of catch.

The human-induced direct and indirect degradation of fisheries resources might cause impacts jeopardizing biodiversity, and ecosystem resilience (Naeem et al., 1994; Perrings et al., 1995). This has led to calls for 'ecosystems approach to fisheries management' in the 21st century[1117]. Escalation of fishing on fishery resources and increased recognition of problems associated with disruption of food web structure has underscored the need for a more holistic approach to management based on ecosystem principles (Fogarty et al, 2000). Christensen et al (1996) define ecosystem management as "... management driven by explicit goals, executed by policies and made adaptable by monitoring and research based on ecological interactions and processes necessary to sustain ecosystem composition, structure and function."

Fish species does not exist independently of its prey or predators; so single species models can only hope to tell part of the story. The challenge is to understand and adopt an ecosystem-oriented approach to managing the environment- an approach that respects the natural boundaries of ecosystems and takes into account some of their interconnections and feedbacks. It is being increasingly felt that the scope of marine resource management must encompass multiple objectives specially preservation of biodiversity and sustainable resource use[1218].

Miller *et al.* (2010) suggest that climate change adds to the inherent uncertainty of fishery management systems and that the solution is a stronger focus and support for "integrative science" methods and processes. In their view, integrative science can assist in evaluating sources of uncertainty and allow "better assessments of behavioural responses of fish, humans and institutions". Johnson and Welch (2010) recommend that for high adaptive strategy countries advancing best practices would be appropriate. This would include countries incorporating larger margins of safety into harvest and effort targets. It would also shift management priority, in their view, from economic profit to ecological stability by taking an ecosystem based approach that includes climate variability.

4. SUSTAINABILITY OF FISHERIES AND THEIR MANAGEMENT

Sustainability is an important idea-the central idea being that a resource is used in such a way that it can be used indefinitely. Fishing is sustainable when it can be conducted over the long term at an acceptable level of biological and economic productivity without leading to ecological changes that foreclose options for future generations. It embraces a multi-species perspective through biodiversity. Effective conservation of the seas essentially entails controlling our use of natural resources so that the web of life needed to maintain the marine and coastal ecosystems, which support the assemblages of species, is not undermined. This is at the core of sustainability. Sustainable use of resources, according to Bruntland Commision (World Commission on Environment and Development, 1987), is thought of as the use of resources today without compromising such use for future generations. During the 1990s it became apparent that integrated management and sustainable development are of key importance to the world's coasts following the Bruntland Report. Consideration of fishing effects on biological communities and ecosystems reinforces the conclusion that a sustainable general increase in the yield of marine fisheries is not the only aim[1319]. To be sustainable, fishing and fishery management must be flexible and responsive to environmental changes as well as biodiversity maintenance.

The issue of fishery management has been discussed extensively by authors like Hilborn and Walters (1992), Agardy (1997), Indicello et al. (1999) and others. The fundamental purpose of fisheries management is to ensure sustainable production over time from fish stocks, preferably through regulatory and enhancement actions, which promote economic and social well-being of the fishermen and industries that use the production. Agardy (1997) has discussed that sustainable use values must reflect changing environmental conditions and planning must take into account ecosystem functioning. In this context, sustainable fishery has been defined to be fishing activities that do not cause or lead to undesirable changes in biological and economic productivity, biological diversity or ecosystem structure and functioning from one human generation to the next. This concept has been developed by Lubchenco et al. (1982). To maintain an efficient allocation of resources and sustain profits, Indicello et al. (1999) has argued that incentives to fish must be brought into line with the biological productivity and ecological viability of fish populations.

Management that focuses on components of ecosystem functioning will improve the sustainability of fisheries. Concepts of ecosystem management and sustainability are not new, although their explicit incorporation into many management goals is fairly recent[1420]. Promoting sustainable fisheries will depend to a large extent, on the renewed commitment to the protection of marine biological diversity[1521]. Larkin (1996) has suggested that the essential components of ecosystem management are sustainable yield, maintenance of biodiversity and protection from the effects of pollution[1622]. Detailed ecosystem goals cannot be universally defined as they depend on many national and regional factors. However, some of the goals, such as sustainability of the desired outputs and conservation of biodiversity are similar in general terms in all regions. These management goals are summarized in the term 'sustainable development' [1723].

The concept of sustainable yield has long dominated the analysis of renewable resources as shown by Schaefer (1954), Beverton and Holt (1957), Gulland (1983) etc. Sustainable use of marine resources is often equated with fisheries of maximum sustainable yield (MSY). MSY is generated from a population growth curve, which is plotted against catch-per-unit effort. If the natural dynamics of a population is known over time, the optimal level of effort, which maximizes return and does not impact population recovery, is targeted.

No resource exists independent of others in an ecosystem. Holling et al. (1995) felt that this extensive connectivity means that renewable resource abundance is tied to a balanced system of exploitation. With growth in human population exerting ever-greater pressure on resources, activities that were perceived as sustainable may lead to overexploitation and permanent ecosystem damage. These non-sustainable courses of action may be perceived as economically viable, but they compromise the ability of future generations to use the resources, directly countering the Bruntland Commission's definition of what is sustainable. Tisdell (1998) has argued that economically viable strategies for harvesting living resources are not the same as ecological ones-in fact, they can directly counter ecologically based strategies. So, both ecological and economic biodiversity aspects must be taken into account in fishery management exercises.

The challenges that climate change adds to fisheries management decision making processes can be summarized along the following lines. First, climate change increases the management uncertainty concerning fish stock productivity, migratory patterns, trophic interactions and vulnerability to fishing pressure (Ling *et al.*, 2009; McIlgorm *et al.*, 2010). Secondly, the effects of fishing, especially overfishing and degradation to the essential habits may also exacerbate the difficulty of fisheries management to take actions that respond to climate change signals, *e.g.*, be slower to recover or less resilient (Turner *et al.*, 2010). Third, where fishing has already exceeded thresholds major shifts may have occurred in ecological systems (Casini, 2009) and climate change may produce additional surprises for management (Peters *et al.*, 2004, Lindenmayer *et al.*, 2010). Fourth, social and economic constraints on fishery management may also add to the complexity and uncertainty about fishing effects (Robards and Greenberg, 2007) but they also raise issues of food security in livelihoods (Badjeck, 2010). Finally, climate change now charges fisheries managers to manage for resilience in ecological and social systems, however, our ability to define what makes a natural or social system resilient is limited (Gibbs, 2009).

5. IMPORTANCE OF BIODIVERSITY AND ENVIRONMENTAL FACTORS AS ECOSYSTEM COMPONENTS

The marine benthos harbours the greatest diversity of any ecosystem on Earth[1824]. Fisheries are an important cause of the biodiversity problem because, according to Hanna (1999), the general focus is on single-species management, slow response to environmental signals, and the patterns of sequential harvesting, overcapacity and pressures on continuing use. It is important to explain better how man's activities affect marine biodiversity and to evaluate the consequences of diversity changes in the coastal ecosystems (Lasserre, 1991). So Heywood (1995) feels that a major environmental concern in the 2000s is the preservation of biodiversity in the context of sustainable development and this is related closely to future options for the management of lands and waters.

New measures must be adapted to serve the needs of ecological and economic sustainability. Their conservation[1925] will depend upon the development of ecologically and economically sound models for management and the effective education of people to the value of biological conservation. Lasserre (1992) has pointed out that significant threats exist from resource exploitation and from other human activities including waste disposal. The necessity of protection and management of biological diversity is now firmly established on the international agenda[2026].

Maintenance of biodiversity has only recently been earmarked as part of ecosystem management[2127]. The need to protect marine biodiversity was appreciated only after concern for the conservation of terrestrial habitats and species first became widespread. The effect of human activity on the seas and oceans is not as noticeable as that on land. For perhaps centuries coastal waters were receiving increasing amounts of human waste, and their fish stocks were being increasingly heavily exploited, without obvious ill effects. Furthermore, there was no long-standing tradition of planning and management of marine areas.

As soon as we harvest one species, abundance of this species changes. Changes are not limited to the target species, but affect other species also via predation and competition. This is of course potentially important from the perspective of the fishery, but also has broader implications, as interactions among species can be complex. There is good evidence of local reduction in species richness following fishing (Moore and Jennings, 2000). There are also several cases where harvesting of predators can lead to major shifts in community composition (Paine, 1980). As noted earlier, in focusing upon the single species target populations themselves, relatively little attention has been diverted at impacts upon their wider ecosystems.

An indicator of the condition of coastal fisheries is the relative abundance of fish stocks at different levels of the food web. In many fisheries, the most prized fishes are the large predatory species high on the food web, such as tuna, cod, hake or salmon. When these 'top predators' are depleted through heavy fishing pressure, other species lower on the food web may begin to dominate the fish catch. This pattern of exploitation was described by Pauly et al. (1998) as *'fishing down the food web'*, and it may signal deterioration in the species structure of the ecosystem [2228].

Another impact on biodiversity due to the exploitation of fish populations is more direct. Fisheries rely on relatively few commercially important species. Five species groups make up 50% of the global total catch, while 200 major stocks account for 77% of landings. It is estimated that the five commercially important targeted fish species require urgent and appropriate management to prevent them from being defined as depleted or over-exploited (FAO, 1997).Many tools and opportunities exist in fisheries management to adopt measures toincrease the resilience of fisheries to climate change. Many of the management actions that assist in coping with climate change are consistent with best management practices for fisheries today. Climate change is another justification for making fishery management policies more resilient and thus resistant to climate change or other alterations. Climate change is a key driver for developing an ecosystem based fishery management system as it exerts a pervasive influence over the whole fished system. Management approaches and policies should be expected to differ in detail due to regional differences. Still they will have an overarching functional similarity as a result of responding to climate drivers of change. Fishery management systems that have already implemented most if not all of the best practices are the most capable to produce positive results from climate adaptation measures. Fishery management systems that lack some elements can still benefit from management actions although the options are more limited and the condition of the ecosystem may limit responses.

It is not clear if fishery management responses can be adequate to adjust to all multiple stressors related to climate change, however it is too early to concede the contest. The fundamental question is whether or not fisheries decision makers can be any more successful in dealing with the challenges of climate change than with other fishery management issues which show mixed results in responding to challenges and opportunities. The UN Environment Program, for example, estimates in a preliminary report on its Green Economy initiative that a global investment of USD 8 billion per year to rebuild the world's fisheries could result in benefits to the global economy of USD 1.7 trillion over the next 40 years (UNEP 2010). The annual investment would be used to reduce excess capacity in the world's fishing fleets, train fishers in alternative livelihoods, set up tradable quota management systems, and designate and manage marine protected areas. These measures are projected to lead to the increase of sustainable harvests in fisheries to 112 million tons annually.

This level of investment could be covered by diverting a portion of the USD 27 billion spent in subsidies (UNEP 2010). Despite what appear to be significant economic and social benefits projected in a move from dysfunctional and quasi-functional fisheries management to functional management there does not appear to be much attention being paid to making the modest investments that UNEP suggests. With such response, it is hard to be sanguine about what to expect when one considers that climate effects on fisheries as we know them are generally expected to be disruptive at best and largely negative in both ecological and social and economic terms (Cheung et al., 2008). Thus, even though the incentive to avoid costs of climate change through adaptation (Costello et al., 2010) seems equally compelling as the incentive to obtain significant benefits by investing in fishery management measures yet it remains to be seen how fisheries management respond.

Another important ecosystem component is environmental variations, to which fishes which are a mobile resource in a flowing opaque medium is sensitive. This greatly complicates the task of estimating annual yields or catches per unit effort (Winpenny, 1991). Fishery scientists have long recognized that the productivities of exploited stocks are sensitive to environmental variability. Environmental factors directly affect individual growth rate of the fish stock. Hofmann and Powell (1998) have given four excellent examples of how environmental variability can affect fisheries recruitment. They argue that the changing nature of marine fisheries requires management that recognizes such environmental effects, suggesting that having identified favourable and unfavourable environmental conditions fishing levels should be adjusted downwards during the unfavourable periods.

Unfavourable environmental conditions like discharge of pollutants are a growing problem. Globally, the number of people living within 100 km of the coast has increased from roughly 2 billion in 1990 to 2.2 billion in 1995 –i.e., nearly 39% of the world's population lives in the coasts (Burke et al. (PAGE), 2000). However, the number of people whose activities affect coastal ecosystems is much larger than the actual coastal population because rivers deliver pollutants from inland watersheds to estuaries and surrounding coastal waters. As coastal and inland populations continue to grow, their impacts-in terms of pollutants loads and the development and conversion of coastal habitats-can be expected to grow as well. Integrating along these themes allows a fresh synthesis and a new paradigm in the management of fisheries.

6. ECONOMIC IMPACTS OF CLIMATE CHANGE ON FISHERIES IN THE DEVELOPING COUNTRIES

In the poorer countries of the world, fishing is often the occupation of families who have generally no other opportunities and it provides their main source of food and income. Decline in the productive capacity of ecosystems can have devastating human costs. Too often, the poor are the first and most directly affected by the degradation of ecosystems. Impoverished people are generally the most dependent on ecosystems for subsistence but usually exert the least control over how ecosystems are used or who reap the benefits of that use. These countries often have huge international debt and are not in a position to buy excess capacity for fisheries, even if, in the longer term, this would increase protein supply. The scale of poverty and reliance on fisheries in the developing countries is also interlinked together. Estimates suggest that 1 billion people in 40 developing countries may lose access to their primary source of protein as a result of overfishing.

A key factor concerning future economic impacts is the need to identify which countries and regions are most vulnerable. Modeling studies have assessed country vulnerability on the basis of exposure of its fisheries to climate change, high dependence on fisheries production, and low capacity to respond. The studies show that climate will have the greatest economic impact on the fisheries sectors of central and northern Asian countries, the Western Sahel, and coastal tropical regions of South America, as well as on some small and medium-sized island states. Indirect economic impacts will depend on the extent to which local economies are able to adapt to new conditions in terms of labor and capital mobility. Change in natural fisheries production is often compounded by decreased harvest capacity and reduced access to markets. Global fish production is forecast to increase more slowly than demand to 2020, and the proportion of production coming from aquaculture is forecast to increase (40). Therefore, zero growth in capture fisheries production will not threaten total supply unduly, but a decline could affect global fish consumption.

Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal feasible means of reducing the impacts of climate change. Fishing and climate change are strongly interrelated pressures on fish production and must be addressed jointly. Loss of biodiversity and reductions in demographic and geographic structure due to fishing result in greater sensitivity of fish stocks and marine ecosystems to climate change. Conversely, climate change can reduce (or in some cases enhance) the productivity of stocks through effects on NPP, reproductive output, growth, and survival. Sustainable levels of fishing (often expressed as reference levels for biomass and fishing mortality) must therefore be adjusted to take such climate-induced changes in productivity into account.

Fish are a component of marine ecosystems, and the continuing development of a precautionary, ecosystem-based approach that goes beyond the assessment and management of just a few commercially important species provides a better basis for incorporating climate-induced changes. The possibility of nonlinear, abrupt changes in productivity and species composition also points to the need for a precautionary approach to fisheries management. Because nonlinear changes may be hard to predict, the management system must be able to respond quickly.Given the complexity and regional variability of marine ecosystems and their responses to climate change, it is difficult to provide detailed management and adaptation strategies for fisheries management. However, it is possible to suggest attributes of management that are likely to be helpful. These include flexibility, adaptability to new information about the marine ecosystem, reflexivity (i.e., continuous evaluation of the consequences of management in relation to targets), and transparency in the use of information and in governance.Fisheries have always been subjected to large natural variability, and fishing communities have in most, but not all, cases been able to adapt to these changes. Management measures should seek to accommodate such autonomous adaptation by retaining flexibility in transitions between alternative livelihoods. Management measures should also avoid historically based schemes (e.g., catch quota allocations) that cease to correspond to changing distributions and population levels. Objectives for sustainable management of fisheries should build-in expected climate change.Changes in the amplitude of climate variability are very likely to have greater consequences than changes in mean values. Extreme climate events have significant consequences for fisheries production in both marine and inland systems.Our present ability to predict regional and global fish production is poor and requires improvement in a number of areas, including the following:

- Models that relate interannual variability, decadal (regional) variability, and global climate change, to make better use of information on climate change in planning management adaptations.

- Observations and models of regional and global NPP. Development of new models for predicting how changes in NPP will pass through the aquatic food chain to fisheries resources.
- Acknowledgment of the consequences of changes in biodiversity for the stability, resilience, and productivity of aquatic systems.
- Greater understanding of the consequences of the trend toward increasing aquaculture for future aquatic production.

It is felt that developing nations should learn from the mistakes made by developed nations. Many developed nations have taken up coastal management retrospectively. If developing nations can learn from this and resist the pressure to build on potentially vulnerable coastal land, they will be able to avoid having to make the tough and costly choices already facing many developed coastal nations (McGlashan, 2000). This reiterates the fact that there can be little doubt that understanding the implications of ecological-economic interactions for fisheries is very important (Hall, 1999).

The important point is the sustenance of such fisheries. There are good practical reasons why one might wish to include species interactions in well-managed fisheries. It is common for several species to be caught with the same fishing gear and it is also impossible to adopt independent harvesting strategies for all the species of interest. This is especially true for fishing in developing countries. Besides this excessive fishing will eventually lead to a decline in catches, which may be masked by a shift in species composition towards lower-value fish (Jennings et al., 2001). The price of fish will tend to rise in the long term with serious consequences for the lower-income groups who are actually engaged in the fishing process.It is hard to be sanguine about what to expect when one considers that climate effects on fisheries as we know them are generally expected to be disruptive at best and largely negative in both ecological and social and economic terms (Cheung *et al.*, 2008).

7. CONCLUSION

Fisheries are a major world industry exploiting natural resources for food. The role that powerful economic incentives play has the power to stop chronic overfishing and to shift the focus of fishery management from development and exploitation to conservation and sustainability[2329]. The improved management of fisheries, which reduces the economic waste arising from overfishing, could realize substantial long-term benefits. Robinson (1980) estimated that possibly some 10-15 million tonnes of additional fish could be landed as a result of improved management.

According to the National Research Council (1995), the current overexploited state of the world's marine fisheries is due to ill-defined property rights and excess fishing capacity. It is true that the results of the past twenty years of management do not show much improvement. Some form of regulation is probably necessary in most fisheries, since unregulated fisheries may suffer from open access problems. e fishery experience highlights the urgent need for research to determine the most appropriate and efficient paths towards ecological and economic sustainability (Charles, 1994). Explicit management goals should be established for fisheries. To achieve this goal, it is necessary to predict how the levels of fish stock in a coastal ecosystem might change naturally or be altered by human action. So models should allow the development and application of new indicators of ecosystem functioning and the dynamics of fish populations to permit assessment of management performance. A new approach pinpoints places where climate change is likely to affect fisheries most. As well as fishers' lives, climate change will affect trade, economies and jobs. 'Vulnerability mapping', as it is called, alerts people to climate-change hot spots where action is urgently needed. Communities can use this approach to help prepare for climate change. Fishing groups in Malawi have now included migration and other ways to adapt to climate change in their plans. Benin, Malawi, South Africa, Cambodia, Indonesia, Malaysia, the Philippines, Brazil, Chile, Italy, Finland and the UK are also using vulnerability mapping. It has great potential for lessening the risks of climate change throughout Central and West Africa, tropical coastal areas in South America and South East Asia.

Undertaking the transition from current fishery practices to ecologically and economically sustainable ones is important for sustainable fisheries and healthier ecosystems. The coupling of fishery management issues more directly with the issues of marine pollution, and biodiversity represents an increasing understanding of the linkages among them. This calls for changing fishery management paradigms towards a more coherent ecosystem approach. An ecosystem – restoration plan is needed which should work on water pollution prevention and biodiversity loss. It is not clear if fishery management responses can be adequate to adjust to all multiple stressors related to climate change, however it is too early to concede the contest. The fundamental question is whether or not fisheries decision makers can be any more successful in dealing with the challenges of climate change than with other fishery management issues which show mixed results in responding to challenges and opportunities. The stakes are high: the future of world fisheries, their associated marine ecosystems and the millions of people that depend on them for food and employment.

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ENDNOTES

1 Aquatic ecosystems, covering two-thirds of our planet's surface, have always been an important source of human food. All aquatic populations show biomass fluctuations. The loss in biomass can be divided into natural mortality and fishing mortality. Effects, which are difficult to quantify, include the effects of over-exploitation of one-species on other species or on whole ecosystems and the genetic effects of overfishing on exploited populations.

2 Coastal areas are diverse in function and form, dynamic and do not lend themselves well to definition by strict spatial boundaries. There are no exact natural boundaries to delineate coastal areas and they can best be viewed in their entirety as special geographical areas wherein the productive and natural defense functions are intimately linked with the physical and socio-economic conditions far beyond the physical boundary.

3 For example, Atlantic halibut once commonly found off New England are now rare. Some fisheries have been subject to severe curtailment and closure: in North America, most notably cod off Newfoundland, groundfish off New England, and some salmon species in the Pacific Northwest. Atlantic salmon and American shad have largely disappeared from many rivers of the eastern United States (Merrett and Haedrich, 1997).

4 In such cases efficient management and sustainable exploitation have been the

exception rather than the rule. Resources have been depleted and have collapsed due to over-exploitation, with severe economic and social consequences for the humans relying on them.

5 This should become a passkey to human and national development, a hope to end poverty, a safeguard to biodiversity and a passage to a sustainable future (World Resources 2000-2001, 2002).

6 The coastal areas of the sea are not pristine, having been affected by man for centuries, mainly in four respects, waste disposal, resulting in pollution, intensive harvesting of various resources of the sea and using coast and near-shore waters for recreational purposes.

7 Graham (1943) was the first to explain how increases in fishing power allowed catches to be maintained or increased even when fish stocks declined. Gordon (1954) provided the economic theory to support Graham's observations. In the 1950s and 1960s, scientific methods of stock assessment and estimation of fishery yields were developed based on growth rates and age composition of the catch (Ricker, 1954,1958; Beverton and Holt, 1957; Gulland, 1983).

8 In cases fishery management have been described as having "reduced numerous fish populations to extremely low levels, destabilized marine ecosystems and impoverished many coastal communities" (Safina, 1995).

9 Management action is taken to implement these strategies. Management actions can be divided into catch controls, effort controls and technical measures. Catch controls limit the catches of individual fishers or the fleet as a whole, effort controls limit the number of fishers in the fishery and what they can do, while technical measures control the catch that can be made for a given effort. These would include mesh size restrictions, fishery closures and fishing seasons.

10 Society's way at looking at marine environment also has changed. International agreements reached over the past two decades increasingly recognize the importance of marine ecosystems and the need to sustain them.

11 This has been reflected in the July 1992 declaration of the United Nations Conference on Environment and Development (UNCED). It has been adopted by a majority of the world's coastal nations and recommends that nations of the globe: prevent, reduce and control degradation of the marine environment so as to maintain and improve its life support and productive capacities; develop and increase the potential of marine living resources to meet human nutritional needs, as well as social, economic and development goals; and promote the integrated management and sustainable development of coastal areas and the marine environment.

12 The stated goals of 'ecologically sustainable development' are: 1. sustainable use of both the species and the ecosystem. 2. maintenance of essential ecological processes. 3. preservation of biodiversity at all levels.

13 Various estimates have been made of the total productivity of ocean systems and the maximum long-term potential catch of marine fishes. Many of the latter estimates are near 100 million tons per year, suggesting that the current annual landings of 84 million tons plus unreported mortality is near the maximum sustainable. However, considering species interaction, global over-fishing and ecosystem degradation, it is possible that, under present management and fishery practices, the current catch cannot be exceeded or perhaps even continued on a sustainable basis. Considering individual stocks globally about 30% percent are over-fished, depleted or recovering and 44% are being fished at or near the maximum long-term potential catch rate.

[14] For example, Kurien (1998) described traditional Asian coastal proverbs that used to guide traditional fishing activities and they are closely related to the ideas of sustainability and ecosystem management.

[15] In recent years arguments for biodiversity conservation and mounting concerns over the implications of biodiversity loss has led to increased calls for a global biodiversity strategy as being essential to ensuring sustainable development (McNeely et al., 1990; IUCN/UNEP/WWF, 1980,1991). Pressure on the marine environment, and in particular the coastal zone, is unlikely to be relived in the foreseeable future. It is estimated that the human population of coastal regions will double by 2020 (IUCN/UNEP/WWF, 1991), placing further demands on the coastal/marine environment as a source of renewable resources, as a sink for waste and as space for urban, industrial and agricultural development.

[16] Concern over the sustainable use of aquatic resources is not new. Recently, FAO's Committee of Fisheries developed the concept of 'responsible fishing' to encompass a broad range of principles for the sustainable management of marine resources, including biodiversity. These principles are intended to ensure the sustained yield of diverse fish stocks from oceanic and coastal fisheries, and to ensure the maintenance of biodiversity. In fisheries, the use of that incorporate interactions between fish stocks and environmental factors, and the use of more selective fish capture methods offer hopes for increasing the sustainability of the harvest and the conservation of marine biodiversity (Heywood, 1995).

[17] A sustainable fishery must incorporate: 1. a whole-ecosystem approach to fish, fishers and environment. 2. understanding and maintaining biodiversity. 3. maintaining aquatic ecosystems at their full productive potential. 4. a continuing flow of high-quality benefits to stakeholders. 5. public awareness of the nature of the resource and flow of benefits.

[18] By some measures the oceans support the highest biological diversity in the world rivaling that of tropical forests and exceeding all other areas in diversity in genera, classes and phyla.

[19] UNESCO Coastal Marine Programme (COMAR) sponsored a conference on Coastal Systems and Sustainable Development where it was stressed that the maintenance of biodiversity in coastal systems is an essential element for sustainability (Postma, 1992).

[20] Concern over the rapid depletion and degradation of the world's biological resources, and the implication of this loss for the global biosphere and human welfare, has been mounting in recent years. As much as 25% of the world's species present in the mid-1980s may be extinct by the year 2015 or soon thereafter (UNEP, 1992).

[21] A major danger is that the continuing loss of our biological wealth will leave us not only with a smaller but also a much less varied stock of global biological resources. Our remaining pool of genetic material will show less variation, there will be less species richness in a given site or habitat and this will put human livelihoods at risk. The concern is that current rates of resource exploitation may be leading to excessive biodiversity loss. Assessing the degree of degradation is a major task.

[22] Uncontrolled exploitation may drive populations so low that even if not exterminated they make take many years to recover. The structure and dynamics of associated food webs may also be altered. Most marine fishes that people catch can reproduce early enough and in sufficient numbers that they should

be relatively easy to exploit sustainably. But this has not prevented humankind from overexploiting even these inherently less vulnerable species. As fishing effort continues to increase, fishing could, especially in combination with other threats eliminate fish species. The principle challenge confronting decision-makers wishing to conserve their marine biological diversity and thus keep options alive for deriving values from the coastal and marine environment is to develop management that allows for optimal resource use while maintaining ecosystem integrity (Agardy, 1997).

23 Conservation and management measures would include all that "are useful in rebuilding, restoring or maintaining any fishery resource and the marine environment" and assure that "irreversible or long-term adverse effects on fishery resources and the marine environment are avoided".

Section 6

Forestry

Chapter 14
Assessing Urban Residents' Willingness to Pay for Preserving the Biodiversity of Swamp Forest

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ABSTRACT

Measuring the biodiversity value in monetary could be useful information for policy-makers to estimate welfare losses caused by biodiversity reductions and perform cost-benefit analysis of biodiversity conservation projects. This study applied the approach of contingent valuation to analyze the Mekong Delta urban households' preferences and their willingness to pay for the program of biodiversity conservation in U Minh Thuong National Park, one of the largest peat swamp forests in Vietnam. The study estimated that the mean WTP of urban residents in the Mekong Delta was about VND16,510 ($0.78) per household per month for all respondents and around VND31,520 ($1.49) after excluding the protest zero and scenario rejecting respondents. Aggregately, they agreed to contribute about $10.97 million annually for the project of biodiversity conservation.

INTRODUCTION

Controlling water flow, preventing from the damage of flood and storm, supporting fisheries, absorbing waste and especially maintaining biodiversity are an example for the important role of natural wetlands. Moreover, wetland regions are places for water transport and recreation while the diverse resources in wetlands could be directly exploited for agriculture, fishing, water supply, wood and wildlife products. The aggregate economic benefit of a wetland's ecological functions, resources and services could surpass the economic value received from the wetland conversion for alternative uses (Wattage, 2002).

One of the largest wetlands in Vietnam are Mekong Delta wetlands, which have great biodiversity, with assisting a large number of herons, egrets, stocks, ibises and some rare species such as sarus cranes, black necked storks, lesser adjutants and

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great adjutants. Specially, the mature semi-natural Melaleuca forest and seasonally inundated grasslands of the Mekong Delta wetlands are the living environments of about 14 globally threatened bird species. Therefore, preserving these wetlands is important or beneficial not only for Vietnam but also for the world. Moreover, there are also a lot of unknown flora and fauna, microorganisms, and genetic resources that are expected to contribute to, for example, the future development of new medicines or coenzymes, which are necessary for biochemical reaction.

Due to an overheated economic development, Mekong Delta wetlands have been dealing with so many problems related to environmental pollution and an increase in wetland destruction, especially, the serious biodiversity loss and degradation. For example, the numbers of endangered species (sarus cranes) in Tram Chim National Park - one of the largest national wetland parks - have rapidly decreased from 1,057 in 1987 to 93 in 2005 (Do and Bennett, 2007; Khai and Yabe, 2014a; 2014b). The degradation of wetland biodiversity is due to an increase in shrimp farming, the conversion of wetlands to agriculture and construction land, war destruction and excessive fuel wood collection. The development of dykes in the Mekong Delta has altered hydrologic conditions and also hence wetland health (Do and Bennett, 2007). To prevent from the biodiversity loss and degradation, the local authorities have proposed plans to use public funding to improve the protection of biodiversity. However, up to now there is little information on the values of biodiversity as well as studies on nature and biodiversity conservation in the Vietnam's literature. Thuy (2007) applied the CV method with five bid-level questionnaires to conduct the study on willingness to pay for the conservation of Vietnamese Rhinoceros and estimate the mean WTP of $2.5 per household. Environmental choice modeling was applied by Do and Bennett (2007) to identify the biodiversity benefits of Tram Chim National Park. The study estimated total benefits of wetland conservation program were about $3.9 million.

Since the information and studies related to the benefit of biodiversity conservation are limited, policymakers cannot answer the question of whether the change in current management practices would generate net social benefits. It is relatively easy to calculate costs of biodiversity conservation program, but hard to estimate benefits. The benefits or design of biodiversity policy could be estimated by studying public preferences on conservation program. However, this is complicated because of the generally low level of awareness and understanding of what biodiversity means on the part of the general public (Christie et al., 2006). Furthermore, although there are a lot of conservation activities especially in biosphere reserves of the Mekong Delta recognized by UNESCO, these are not strong or powerful enough to enlarge or improve the quantity and quality of biosphere reserves because of government budget constraint or the low level of support from local residents and authorities. The studies are needed to be done to answer the question of whether is worthy investing more financial resources in conserving biodiversity in these biosphere reserves.

Moreover, to avoid biodiversity degradation Vietnam's government began to implement policies and laws about biodiversity conservation in early 1960s. Subsequently, many legislative developments and institutional reforms have developed the aims of conservation and sustainable use of biodiversity, including: Forest Protection and Development Law in 1991 (amended in 2004); Land Use Law in 1993 (amended in 1998 and 2003); Environmental Protection Law in 1993 (amended in 2005); Fishery Law in 2003; and the most recently, the Biodiversity Law was approved by the National Assembly in November 2008. Vietnam participated in the Convention of Biological Diversity in 1994, and to fulfill its commitments and obligations under the Convention, in 1995 the government of Vietnam approved the first

National Biodiversity Action Plan (NBAP). The NBAP and its successors have directed biodiversity conservation activities in Vietnam.

In 2006, the second NBAP (to 2010) and its orientation towards 2020 (known as NBAP 2007) was prepared and approved on 31st May 2007, ensuring conservation objectives are integrated into the country's socioeconomic development. NBAP 2007 consists of 5 major goals each with several specific objectives. Key objectives include: consolidation and development of the special-use forest system; regeneration of 50% of degraded watershed forests; effective protection of valuable and endangered plants and animals threatened by extinction; establishment of 1.2 million hectares of internationally and nationally important protected wetlands and marine protected areas; regeneration of 200,000 hectares of mangrove forests; development of demonstrations for sustainable use of plants and animal resources; control, prevention, and ceasing exploitation, trade, and consumption of endangered wildlife species; examination of 100% of national imported species and gene resources; education and public awareness-raising about biodiversity conservation so that 50% of the population regularly receive information about biodiversity. However, there remain some difficulties and obstacles in implementing the NBAPs, such as: poor cooperation between ministries, sectors, local authorities, and biodiversity management agencies; inadequate mechanisms for benefit-sharing; weak community participation in biodiversity conservation, and; especially budget constraints.

In this study, we try to estimate total economic values of proposed biodiversity conservation program in U Minh Thuong National Park using the approach of CV method. The study might partly seek to answer the above questions and solve these mentioned problems. The research also provides policy makers and concerned people more information about residents' attitudes toward environment and natural resources as well as the benefits of biodiversity conservation.

LITERATURE REVIEW

There are a number of previous studies using the contingent valuation (CV) method to estimate the benefits of wetlands. Costanza et al. (1989) estimated the WTP value to preserve wetlands for recreational purposes in Terrebonne Parish, Louisiana. The study estimated that the total present value of an average acre of natural wetlands in Louisiana were US$2429–6400 per acre (assuming an 8% discount rate) to $8977–17000 per acre (assuming a 3% discount rate). Hoehn & Loomis (1993) conducted a wetlands maintenance program, a wetlands improvement program, contaminant maintenance program, a contaminant reduction program and a salmon improvement program. The study investigated that under the existing environmental agenda for the San Joaquin Valley, wetland acreage was declining, wildlife was exposed to contaminants from agricultural drainage at increasing rates, and the productivity of native fisheries was declining. WTP ranged from $63 to $184 for single-program agendas, from $178 to $350 for two-program agendas, and from $224 to $446 for three-program agendas in1989 US dollars.

Beran (1995) used CV questionnaires to estimate the passive use values associated with preservation of freshwater wetlands in South Carolina. The study revealed that mean WTP ranged from a one-time contribution of $6.03 to $45.4 according to the estimation technique and the type of wetland valued, and a total value of WTP for South Carolina residents was $3.7 million. Kosz (1996) examined the costs and benefits of different proposed projects of the Donau-Auen wetlands east of Vienna. The study applied a CM method to estimate the WTP for wetlands in an unchanged natural state. The results indicated that the Wildungsmauer power station had the highest present value (37.7 million ATS), followed by the Wolfsthal station (16.5 million), and then the establishment of the national park (11.5 million).

The study by Langford et al. (1996) applied the approach of triple bounded, dichotomous choice (DC) to discover whether the respondent agreed to the idea of paying some amount in extra taxation over the following year to preserve the Norfolk Broads wetland. The results showed that the median willingness to pay (WTP) to preserve the Norfolk Broads wetlands from seawater inundation was estimated to be in the range of £ 20.30 to £ 93.70 (1992 British pounds), or $38.65 to $178.40 U.S. dollars. Mahan et al. (2000) estimated the value of wetland amenities of wetlands in Multnomah County, a metropolitan area in Portland, Oregon using a hedonic property price model. Results revealed that increasing the size of the nearest wetland to a residence by one acre increased the value of the residence by $24 and reducing the distance to the nearest wetland by 1,000 feet increased the value by $436.

The study by Pate and Loomis (1997) applied CV questions to estimate average and aggregate annual WTP for wetland improvement, contamination control, and salmon improvement programs in the San Joaquin Valley, California. The research calculated that average annual household WTP for the wetland improvement program ranged from $67.80 to $215.55 and aggregate annual WTP estimates for the program ranged from $81 million to $2,357 million in 1990 U.S. dollars. Average annual WTP for the contamination control program ranged from $51.92 to $233.86 and aggregate annual WTP estimates for the program were between $62 million and $2,490 million. The study also found that respondents' geographic distance from the environmental amenity did affect WTP estimates for the wetlands habitat and wildlife, and wildlife contamination control programs. The recent study by Chen and Jim (2010) analyzed Guangzhou residents' motivations and WTP for an urban biodiversity conservation program in the National Baiyun Mountain Scenic area. The research estimated the median WTP of $19.5 per household per year and the total value of about $38.2 million annually to contribute the urban conservation project.

Research Area and Data Collection

U Minh Thuong National Park is one of two largest areas of peat swamp forest in Vietnam. Biodiversity conservation in this region has been assigned a national priority since it can buffer the negative effects of the Mekong River floods, recharge aquifers and provide a unique environment for many wetland species. With a total area of 8.038 ha and a buffer zone of 13.069 ha, the national park is a home of many diversified plants and animals including 243 plant, 32 mammal, 151 bird, 34 reptile, 7 amphibian, 34 fish and 181 insect species. Forty of these are listed as endangered species in the Vietnam Red Book (Dang 2009).

Although the government has declared the protected zone, U Minh Thuong National Park is still under serious threats to biodiversity such as an increase in human encroachment on and disturbance of wildlife habitats by converting the forest land into agriculture and construction land, environmental pollution caused by subsistence wastes, industrial wastes, use of insecticides, herbicides and toxic rat baits, illegal wildlife hunting and trade, etc.

Primary data were collected by randomly interviewing local citizens face-to-face in the urban area of Can Tho city, representing the largest city in the Mekong Delta and the urban region of Kien Giang province where U Minh Thuong National Park is located. The time of survey took about 3 mouths from January to March 2013 and was divided into two main periods. The first one was the pilot-survey, in the first week of January 2013. The pilot surveying and pretesting are essential elements in any contingent valuation study (Bateman et al., 1995). The aims of this interview are to refine the questionnaire, format bid starting point more clearly and concisely, and also help interviewers get used to and understand the content of questionnaire. After the interviewers are trained, there are about 50 households interviewed in this period. The revised questionnaire is used in the second period. The sample was composed of 366 respondents, 215 in Can Tho and 151 in Kien Giang. To make a good CV questionnaire without cheap talk bias, the content of questionnaire is formed based on the suggestion of Carson (1991), and Cummings and Taylor (1999). We first examine how the respondents concern environmental problems in the country and recognize respondents' attitude toward biodiversity conservation project. Secondly, the plan of proposed project is introduced with the payment vehicle and provision rule. Finally, socioeconomic information of respondents are collected.

The single-bound dichotomous choice contingent valuation questions were used in the study. Before the CV question was asked, the current conditions, biodiversity as well as the benefits of U Minh Thuong National Park were introduced. Then, we identified some threats of biodiversity loss such as encroachment, disturbance of vegetation, environmental pollution, wildlife hunting, and trade occurring in this area. A hypothetical conservation program was proposed to prevent from biodiversity loss in the national park. Biodiversity will continue to degrade more seriously without this conservation project. The study proposed funding a biodiversity conservation project to increase the number of plants and animals in U Minh Thuong National Park or at least keep them from declining every year. The conservation fund could then request international organizations to provide the same amount of money or more compared with the contributions of residents. The raised money would be only used for conservation activities in U Minh Thuong National Park (See the section of CV question for more details in the Appendix). The payment vehicle was used as voluntary continuous donation, contributed through a monthly water bill for three years, which could catch the present value of preferences for biodiversity conservation and also prevent potential protests due to compulsory payment like taxes (Rolfe et al., 2000). Each household was interviewed whether he/she would be willing to contribute the biodiversity conservation fund a certain amount of money every month as surcharge on his/her household water bills for the next three years. The admissible answers were 'yes' or 'no'. Five different bid values of VND10,000, VND35,000, VND60,000, VND85,000 and VND110,000 were chosen for the study. These values are equivalent to values in US dollars[1] of $0.47, $1.66, $2.84, $4.21 and $5.20, respectively. Each household was randomly interviewed whether he/she would be willing to contribute one of these bid values and answered whether he/she accepted only one bid value. For example, the respondent was asked 'Would you be willing to pay VND10,000 every month for biodiversity conservation program in U Minh Thuong?' If the answer was 'yes', the list of 'yes' reasons was then presented. If the response was 'no', the list of 'no' reasons was then introduced and an open-end question was also asked whether a respondent would like to contribute another lower amount of money to identify the categories of protest zero, valid zero and WTP less bids.

METHODOLOGY

Willingness to Pay and Willingness to Accept

Based on the theory of Hicksian surpluses, the compensating and equivalent measures are popularly used to measure the welfare change of non-marketed goods. The purpose of nonmarket valuation techniques is to estimate the welfare change of the individuals in the absence of the competitive market. The equivalent measures are considered as the payment of compensation that would bring the consumer to subsequent welfare level if the change did not happen, while the compensating measures are identified as the payment of compensation which would keep the consumer at the initial welfare level after the change occurred. WTP is the amount of payment that the consumer is willing to pay for the better quality of the environment while WTA is the amount of compensation that consumer is willing to accept the worse quality of the environment. The equivalent measure uses the subsequent welfare level as a base level while compensating measure uses the initial welfare level as the reference level. WTP and WTA may be either Hicksian equivalent or compensating measure of welfare change depending on the situations that the consumer deals with.

Total Economic Value

The benefits of conservation projects could be measured using the theory of total economic value including use values and non-use values (bequest values, option values and existence values). The CV method is a stated preference method popularly applied to estimate total value of environmental resources and its non-use components unable to be identified by indirect methods relying on revealed preference.

A theoretical basic for conceptualizing total economic value and its non-use components could be clearly understood if the definition of each of these concepts is identified. Total economic value includes existence value and several categories of use value. When uncertainty is introduced into the model, benefit values become ex-ante implying that individual's expected benefits are based on what is known at the time of valuation rather than after he/she has experienced the choice (Randall, 1991). The CV method could be used to elicit option prices from households. The term "Option price" has been used to describe the maximum sure payment (Graham, 1981). "Option value" has been applied to the case where an individual who is uncertain as to whether he will demand a good in some future periods is faced with uncertainty in the supply. Option value is the excess of option price over the expected consumer surplus given that the good is supplied and this value can be either positive or negative (Freeman, 1985). According to Randall (1991), the total value framework allows the researchers to estimate total value including various categories of use values and existence values. If estimates of particular component values are needed, a sequential piecewise strategy could be applied.

Existence values are considered as the WTP for the knowledge that a particular level of environmental quality exists, regardless of any present or anticipated use by the individual. According to Mitchell and Carson (1981), existence value can be derived from knowing that the resource is available for others (vicarious consumption) or ecological integrity is being preserved (stewardship). Bequest values represent the value of utility gained by preserving a resource for future generations. Some treat this value as intergenerational component of option value.

Nonmarket Valuation Methods

Recently, the measurement of non-market value has received attention by many policy makers. In cases of the absence of market, the CV method is popularly and frequently applied to assess the value of non-market resources and public goods. The CV method is defined as any approach to valuation which relies upon individual responses to contingent circumstances posited in hypothetical choice context.

The curve of total value is considered as an indifference curve between numeraire good and the quantities of a particular good, service or amenity passing through the origin of graph where quantity in increasing amounts is given in the horizontal axis and decreasing amounts in numeraire good is presented by the vertical axis. Since the curve of total value of a consumer for a non-marketed good is not ordinarily observable, the CV method could be applied to estimate the value for such goods. The objective of CV method is considered as a tool of Benefit Cost Analysis to measure aggregate benefits.

In 1947, Ciracy-Wantrup primarily proposed the approach of direct interview or the CV method to measure the value of natural resources that do not exist in the market (Zoysa, 1995). Later, Davis (1963) used this basic direct interview foundation for bidding methods by estimating the benefits of outdoor recreation in Maine backwoods region. The study written by Randall and Eastmen (1974) is considered as one of the most influent studies in the early years. The study valued the air visibility benefits in the Four Corners area. One of the appealing aspects of the CV method is its capability of dealing with passive use values; which other demand revealing methods may be less capable of doing. The majority of the pioneering methodological works was applied by Randall et al. (1981). Extensive evaluations of this technique were applied in the study by Cummings et al. (1986) and Mitchell and Carson (1989).

The application of CV method is well accepted and popularly applied to deal with the compensating and equivalent measures of welfare changes. The CV survey mainly aims to get an accurate estimate of benefits (sometimes cost) of a change in the level of allocation of some public good. There is a wide variety of approaches for valuing contingent markets.

1. Using an open-ended question in which the respondent is simply asked to claim his/her WTP (WPA).
2. Using the questions in sequential bids in which respondents are asked whether or not they would pay or accept some specified sum (the question is then repeated using higher or lower amount, depending on the initial response)
3. Using a dichotomous choice question in which the respondents is asked only whether or not they would pay or accept a single specific (The sum is varied across respondents)

Sine sequential bidding is not easy to collect in case of mail and telephone surveys and open-ended formats usually create "noisy" data sets, the dichotomous choice (or referendum) format is the most popularly applied. In the referendum question a single specific sum is offered (offer price) to respondents and their yes/no response to the offer is recorded. However, the valuation information in yes/no responses is diffuse and general since the only information revealing respondents' value is higher or lower than the offered threshold. In order to obtain the correct WTP of individuals, The requirement of a large number of observations and a well specified empirical model are very necessary and important (Cameron and Huppert, 1991)

The dichotomous choice contingent valuation method has several advantages over other elicitation techniques such as bidding games or payment cards (Mitchell and Carson, 1989). The referendum format of dichotomous choice CV method is a convenient method for respondents to declare their WTP, closely related to the day to day decisions, made in the regular market or voting booth, and can be easily included in mail survey which allows the respondents to make their decisions with less confusion. Further, this approach is also incentive compatible and is less subject to strategic response that other methods (Hoehn and Randall, 1989).

Estimation of Dichotomous Choice Contingent Valuation

A binary choice referendum type model is applied to identify preferences for preserving biodiversity. This approach has received attention since it creates a scenario for each consumer which is similar to that encountered in market transactions (Cameron, 1988). In dichotomous choice models, a hypothetical price is presented and the respondent makes a decision whether to answer "yes" or "no" to the offered price. In such cases respondents' willingness to pay is unobservable. Therefore, an important assumption is that although the utility function is known to the individual with certainty, it is not directly observable to third-parties, and is hence treated by the researchers as an unobserved random variable. This allows us to incorporate the stochastic element of the binary response model.

To make it simple, we suppose an individual derives utility from consuming an environmental good (biodiversity) and money income. The environmental good is denoted as Q_b where Q_b is zero if the quality of environmental good remains in a status quo point and Q_b is one when the quality of environmental good obtains improvements (individual is willing to pay for conserving biodiversity). Utility function for the individual is:

$$U\left(Q_b, I, Z\right) \quad (1)$$

where Q_b is the quality of environmental good, I is the income of an individual, and Z is a vector of individual's characteristics (e.g., age, gender, education). If an individual is willing to preserve biodiversity, his/her utility is given as follows:

$$U_i^1 = U\left(1, I, Z\right) > U_i^0 = U\left(0, I, Z\right) \quad (2)$$

The equation (2) is under the important assumption of a stochastic component in individuals' preferences which is unobservable due to their characteristics in responses to alternatives. The general form of random utility function can be presented as:

$$U_{ij} = \bar{U}_{ij} + \varepsilon_{ij} \quad (3)$$

where is a deterministic part and ε_{ij} is a stochastic part. The function of attributes of the alternatives for the individuals $\left(U_{ij}\right)$ is specified as:

$$U_{ij} = X_{ij}\alpha \quad (4)$$

where X_{ij} is a vector of explanatory variables in the model and α is a vector of conformable parameters. An individual has two alternatives: to consume the high quality of the biodiversity $\left(Q_b^1\right)$ or to consumer the poor quality of biodiversity $\left(Q_b^0\right)$. He/she can select between Q_b^1 and Q_b^0 where $Q_b^1 > Q_b^0$. The utility functions can be specified as:

$$U_i^0\left(Q_b^0, I, Z\right) = V_i^0\left(Q_b^0, I, Z\right) + \varepsilon_i^0 \quad (5)$$

$$U_i^1\left(Q_b^1, I, Z\right) = V_i^1\left(Q_b^1, I, Z\right) + \varepsilon_i^1 \quad (6)$$

where ε_i^0 and ε_i^1 are independent and identically distributed random error terms. In the data of dichotomous choice form, each individual is confronted with a threshold value M_i. The utility function of an individual who is willing to pay the amount of M_i for conserving biodiversity could be presented as:

$$V_i^1\left(Q_b^1, I - M_i, Z\right) + \varepsilon_i^1 > V_i^0\left(Q_b^0, I, Z\right) + \varepsilon_i^0 \quad (7)$$

The WTP of an individual for conserving biodiversity is given as follows:

$$WTP = \Delta V = V_i^1\left(Q_b^1, I - M_i, Z\right) + \varepsilon_i^1 - V_i^0\left(Q_b^0, I, Z\right) - \varepsilon_i^0 \quad (8)$$

where ΔV is the utility difference in discrete choice responses. If we define $\gamma = \varepsilon_i^1 - \varepsilon_i^0$, the cumulative distribution function $\left(F_\gamma\left(.\right)\right)$ for the random variable is given as:

$$Pr = F_\gamma\left(\Delta V\right),$$

with

$$\Delta V = V_i^1\left(1, I - M_i, Z\right) - V_i^0\left(0, I, Z\right) \tag{9}$$

If a functional form for the utility difference and the random variable (γ) is specified to be consistent with the utility-theoretic framework, the dichotomous choice approach is consistent with the outcome of a utility maximizing choice (Hanemann, 1984).

Estimation of Willingness to Pay for the Dichotomous Choice Survey

The unobserved dependent variable is supposed to be the respondents' true willingness to pay (Y_i) for the environmental good. Y_i is conditional on a vector of explanatory variable (X_i) normally distributed with a mean of $\left(X_i, \alpha\right) = X_i\alpha$. The functional form of Y_i is specified as follows:

$$Y_i = X_i^{'}\alpha + \varepsilon_i \tag{10}$$

where X_i is a vector of explanatory variables, α is the parameter vector and ε_i is independently, identically distributed with mean zero and standard deviation σ. Each respondent is assumed to be assigned a randomly chosen threshold price M_i. Although Y_i is unobserved, it is identified through a discrete indicator variable H_i such that:

$$\begin{aligned} H_i &= 1 \; if \; Y_i > M_i \\ &= 0 \; otherwise \end{aligned} \tag{11}$$

If the error of ε_i is assumed to be a standard normal distribution, the probability that an individual is willing to pay the amount of money (M_i) for preserving biodiversity can be written in the following form:

$$\begin{aligned} Pr\left(H_i = 1\right) &= Pr\left(Y_i > M_i\right) \\ &= Pr\left(\varepsilon_i > M_i - X_i^{'}\alpha\right) \\ &= Pr\left(\frac{\varepsilon_i}{\sigma} > \frac{M_i - X_i^{'}\alpha}{\sigma}\right) \\ &= 1 - F\left(-\Delta V\right) \end{aligned} \tag{12}$$

If an individual makes a decision to stay at the reference level (U^0) of the environmental quality and rejects to pay the threshold price, the probability of a "no" response is expressed as:

$$\begin{aligned} Pr\left(H_i = 0\right) &= Pr\left(Y_i < M_i\right) \\ &= Pr\left(\varepsilon_i < M_i - X_i^{'}\alpha\right) \\ &= Pr\left(\frac{\varepsilon_i}{\sigma} < \frac{M_i - X_i^{'}\alpha}{\sigma}\right) \\ &= F\left(-\Delta V\right) \end{aligned} \tag{13}$$

where $\frac{\varepsilon_i}{\sigma}$ is assumed to be distributed in the form of a standard normal distribution with mean zero and a standard deviation (σ) and *F(.)* is defined as the cumulative density function for the standard normal distribution. The probability is rewritten as follows:

$$Pr\left(H_i = 1\right) = 1 - \left(\frac{M_i - X_i^{'}\alpha}{\sigma}\right) \tag{14}$$

$$Pr\left(H_i = 0\right) = \left(\frac{M_i - X_i^{'}\alpha}{\sigma}\right) \tag{15}$$

So the log-likelihood function is formed as:

$$logL = \sum_{i=1}^{N}\left[\begin{aligned} &\left(H_i\right) log\left\{1 - F\left(-\Delta V\left(.\right)\right)\right\} + \\ &\left(1 - H_i\right) log\left\{F\left(-\Delta V\left(.\right)\right)\right\} \end{aligned}\right] \tag{16}$$

And also by:

$$logL = \sum_{i=1}^{N}\left[\begin{array}{l}(H_i)log\left\{1-\left(\frac{M_i - X_i^{'}\alpha}{\sigma}\right)\right\}+\\(1-H_i)log\left\{F\left(\frac{M_i - X_i^{'}\alpha}{\sigma}\right)\right\}\end{array}\right] \quad (17)$$

The expected WTP or $E(Y_i)$ can be obtained by estimating the log-likelihood function in the dichotomous choice models. The probit and logit model are commonly applied to analyze the dichotomous choice format of contingent valuation method. (Cameron and James, 1987; Cameron, 1991; Sellar et al., 1986). If the cumulative distribution function (F(.)) in the standard normal distribution is considered as the proper tool to analyze the data in the dichotomous choice form, specifying the functional form for the model consistent with the economic theory is a very important. The maximum utility function of an individual is assumed to be linear in parameters although it can be either linear or non-linear in explanatory variables (McFadden, 1976).

In the dichotomous choice type data, the derivation of the expected willingness to pay can be obtained by numerical integration over a continuum of values from zero to the maximum level of M_i (the offered thresholds). The average WTP for the environmental good is as follows:

$$E(WTP) = \int_0^{\infty}\left[1-F\left(-\Delta V(.)\right)\right]dWTP - \int_{-\infty}^{0}F\left(-\Delta V(.)\right)dWTP \quad (18)$$

When the WTP is constrained to be non-negative, the equation (18) reduces to the equation (19), where infinity is replaced by a maximum offered price (Hanemann, 1989). There is distinction between the two main possibilities for estimating $E(WTP)$ as a non-negative number. The integral given in the equation (18) is evaluated over all positive real numbers as the second part of integral reduces to zero while the integral given in the equation (19) is truncated at the maximum offered price. The main argument for the maximum bid truncation is that since no information is available beyond the maximum bid level, it should be truncated at M_{max} as this restricts the estimation of WTP to the range considered in the survey. Further, truncation at infinity is not possible because there must be some maximum level above which *WTP* is not affordable for improvement of the environmental quality (Sellar, et al., 1986).

$$E(WTP) = \int_0^{M_{max}}\left[1-F\left(-\Delta V(.)\right)\right]dM \quad (19)$$

In the economic theory, the equation (19) is considered as the Hicksian measure of welfare changes if a consumer is willing to pay for preserving biodiversity. A total value function can be obtained by estimating the equation (19) at different levels of quantities (Q_i). A demand curve can be derived by taking the first derivative with respect to Q_i. The marginal value curve or the inverse Hicksian demand function is given as follows:

$$Marginal\ value\ curve = \frac{\partial E(WTP)}{\partial Q} \quad (20)$$

The probability of a "no" response is expected to increase with the magnitude of suggested price of biodiversity conservation (M) and to decrease as the quality of biodiversity increases or the costs of conservation decreases. This can be performed in the following formula:

$$\frac{\partial E(WTP)}{\partial Q} > 0 \tag{21}$$

$$\frac{\partial^2 E(WTP)}{\partial Q^2} < 0 \tag{22}$$

Therefore, Hicksian demand function being positive and downward sloping satisfy the theoretical restrictions. In this study, we used the logistic function, which is relatively easier to compute than the approach of probit function. The following form of logistic function could estimate these coefficients:

$$\Pr(H_i = 1) = \frac{1}{1+\exp(-\Delta V)} = \frac{1}{1+\exp-(\alpha+\beta_1 BID+\beta_2 X)} \tag{23}$$

where α and β are coefficients to be estimated and *BID* is the amount of given money the respondents were asked to pay. The mean and median WTP are equal to each other and calculated by the following estimator:

$$Mean\ /\ Median\ WTP = -\frac{\left(\hat{\alpha}+\hat{\beta}_2\bar{X}\right)}{\hat{\beta}_1} \tag{24}$$

Validity, Reliability and the Biases of the CV Method

As aforementioned, The CV method has been dramatically increasingly applied to value the public goods in the recent years. The application of more sophisticated CV survey designs, the issue of random behavior or the estimated methods have been also largely improved. Especially, the recent CV method mostly focuses on estimating the validity and reliability of results. Random behavior is considered to be the antithesis of validity and reliability. Validity depends on the difference between the good or attributes that which we want to estimate and that which we actually estimate. The reliability is the error term in the estimated model. The estimated value of the error term is a non-random variable, likely resulting in the present of biases in the analysis.

We can test validity by examining whether the estimations of the model are similar to other estimations as predicted by theory. The CV method should comply with theoretical expectations (theoretical validity) and should also be accurately agreed with other estimations of the model (convergent validity). Bateman et al. (1993) recommended a further variant of this approach to check the explanatory power of the bid functions.

Another problem of CV method is that the large number of zero WTP values and the high variance in the answer of CV question might cause the low value of Pseudo R^2. According to Mitchell and Carson (1989), the minimum Pseudo R^2 value is considered acceptable to be at least 0.15. However, psychologists stated that the information or decision based on the value of Pseudo R^2 is limited in the very nature of social survey techniques (Bateman et al., 1993).

Based on the assumptions of economic theory, the strategic behavior in the CV method is a function of the respondents' perceived payment obligation and the respondents' expectations about provision of a public good. Following the principle of strategic behavior, an individual have tendency to accept the amount of WTP that is different from their true WTP amounts with aiming to affect the provision of the public goods. However, this does not produce any problems regarding to private good since the provision is not a matter at all.

The study written by Samuelson (1954) about the provision of public goods revealed that respondents could not be expected to disclose their true WTP for strategic reasons. Some tests are available to get control of strategic behavior. The simplest strategy is to use both open-ended and closed-ended questions in the CV survey.

Although the good is desired, we do not expect to experience many unusually large WTP amounts. We also note that if the payment is thought to be probable, there is a tendency to give a zero WTP value. Mitchell and Carson (1989) investigated that the percentage of respondents giving very large monetary amounts is very small, while the percent of respondents giving a zero WTP amounts is fairly large.

Moreover, the CV method also deals with many theoretical and practical difficulties. Several potential sources of bias are caused by the nature of the CV technique and the survey instrument. Among of many biases, some should be essentially considered as hypothetical, strategic, starting point, information, sample-related, and the vehicle biases (Edwards and Anderson, 1987). In most cases, the problem of starting-point bias could be caused by the value selected has an appreciable impact on observed final bids. There are two problems with starting-point bias. The estimate process stops before the true bid is identified if the starting point is far away from the true value. The starting value also conveys information to the respondent about expected or reasonable bids and, thereby, affects the result of final bid value. The information transfer effect is related directly to the initial or starting bid amount.

The estimated WTP value different according to the method payment is known as vehicle bias. The response might not be the same between the question asked the respondents how much in increased price they would be willing to pay in the form of an increased price and the question asked how much they would pay via other methods. The vehicles popularly applied in CV are higher prices, user fees, utility bills, entrance fees, and taxes.

Respondents' values may be changed according to the amount of information about proposed situation they receive. For instance, if information on average price is provided, the respondent may have a different value compared with they are not given information about the average price. This problem is named as information bias. If respondents pay no attention to important information or misunderstand unimportant information, the effect of overloading information may happen. It is very necessary to make the definition of sustainability and quality, decisions about the sampling frame, and attempts to obtain valid WTP responses and non-responses. Although the sampling error problems should not be taken lightly, non-response is probably a much greater source of bias in survey research (Cochran, 1983). Whether or not sampling errors exist, systematic differences between respondents and non-respondents usually invalidate inferences based solely on data from respondents. This could be evaluated by sub-sampling at least 10 percent of the non-respondents when testing for sampling bias.

Sample selection bias concerns differences in behavioral parameters that weight the determinants of behavior. This happens when the probability of obtaining a valid WTP response among sample elements is related to the respondent's value for the good. Field interviews are generally free of sample selection bias because there is less potential for non-respondents to be consciously self-selected. Edwards and Anderson (1987) showed various sources that could influence the sample selection bias and two parametric procedures that test for their occurrence. They also provide an illustration of the magnitude of nonresponse bias in estimates of aggregate benefits. Mitchell and Carson (1989) demonstrated various sources of bias and their magnitude along with methodological problems and possible treatments. Thus in order to decrease bias problems into an acceptable level, the questionnaire must be revised significantly after the results of the pilot survey and comments from the focus group.

RESULTS AND DISCUSSION

Table 1 shows the probability of answering 'no' increases as the amount of money the respondents are asked to pay increases. About 68.6%

Table 1. Respondents refusing the discrete choice amount or refusing to pay any amount for biodiversity conservation

Bid Value (VND)	Observations	Refusals to the Discrete Choice Question		Refusals to Make Any Positive Payment ᴪ	
		Number	Percent (%)	Number	Percent (%)
10,000	76	33	43.4	28	36.8
35,000	77	48	62.3	28	36.4
60,000	74	55	74.3	29	39.2
85,000	72	59	81.9	32	44.4
110,000	67	56	83.6	27	40.3
Total	**366**	**251**	**68.6**	**144**	**39.3**

Note: ᴪ The respondents answered 'no' in the discrete choice question and also did not contribute any lower money in the open-end question.

Source: Own estimates; data appendix available from authors.

of respondents disagree to pay the given discrete choice amount, and 39.3% of those are not willing to pay any positive amount. Possible explanations for the high number of refusals and zero responses may be that respondents are not familiar with this kind of survey, the study might be too hypothetical or the scenarios could be too unspecific and simplistic. Interviewees who do not agree to pay the amount of money given in the questionnaire were asked why they had responded 'no'. Table 2 gives the overall frequencies of answers from a given list of reasons.

Table 2 reveals reasons for refusing to pay the given discrete amount of money. About 51 percent of respondents cannot afford to pay or have not space income to contribute towards the fund of biodiversity conservation (reason 1). Such high percentage of unwilling-to-pay reason due to the income constraint is consistent with other survey study in developing countries. The study on saving the Philippine Eagle by Harder et al. (2006) showed a 62 percent while the study on Vietnamese Rhinoceros conservation by Thuy (2007) revealed about 41 percent of respondents refusing to contribute the conservation program due to income constraint. The second highest-cited reason accounted for 16.3 percent of respondents who think that the biodiversity conservation program should be the government' responsibility since it has money from tax revenues while about 12 percent of unwilling-to-pay respondents with the reason of distrusting the institutions that will handle the money for this conservation work.

Table 2. Respondents giving reasons for refusing to pay the given discrete choice amount

Reason	Number	Percent (%)
1 = I cannot afford to pay/I have no spare income.	128	51.0
2 = I feel the environmental improvement of U Minh Thuong is unimportant.	3	1.2
3 = Being far from the place, I feel paying anything is irrelevant to me.	13	5.2
4 = I do not believe paying will solve the problem.	18	7.2
5 = I feel this improvement will take place without my contribution.	7	2.8
6 = I do not trust the institutions that will handle the money for this conservation work.	30	12.0
7 = It should be the government's responsibility since it has money from tax revenues.	41	16.3
8 = Other reasons.	11	4.4

Source: Own estimates; data appendix available from authors.

This study follows the other previous CV studies to discriminate between valid and 'protest' zero bids. The respondents who are not willing to pay any positive bids with the reason 4 (I do not believe paying will solve the problem), 6 (I do not trust the institutions that will handle the money for this conservation work) and 7 (It should be the government's responsibility since it has money from tax revenues) are listed into the category of 'protest vote' or none-zero value. The percentages of respondents in the protest bid, valid no and positive bid categories are performed in Table 3.

Table 3. shows about 60.7 percent of respondents willing to pay some positive amount for conservation program while about 29.2 percent of respondents agree to pay less than the bid values (The respondents who disagreed to pay the amount of money given in the questionnaire but accepted to contribute a smaller amount of money) and around 24.6 percent of respondents are categorized as valid zero bids (the respondents were not willing to pay any amount of money for conservation program with any other reasons excepting the reason 4, 6 and 7). The study also shows that the proportion of protest bids averages 14.8 percent of all responses. Such figure is somewhat consistent with other results in the literature. Kirkland (1988) has 18 percent of protest responses in his study, about 24 percent are determined by Sappideen (1992) and 28 – 31 percent of protest bids in the study by Jakosson et al. (1996). According to Moser and Dunning (1986), the high level of protest bids reveals that some questions could be misunderstood; the respondents have troubles to understand the study scenario or are not convinced that the proposed project becomes real.

Table 3. The category of protest bid, valid no and positive bid respondents

	Number	Percent (%)
Protest zero bids (1)	54	14.8
Valid zero bids (2)	90	24.6
WTP less bids (3)	107	29.2
Willing to pay discrete choice amount (4)	115	31.4
Willing to pay some positive amount (5)	222	60.7

Note: (5) = Total observations – Protest zero bids (1) – Valid zero bids (2)

Source: Own estimates; data appendix available from authors.

Table 4 shows the socio-demographic description of the respondents. The age of surveyed respondents ranges from 20 to 87 years with the average age of 50 years and about 62 percent of respondents are female. The high percentage of female respondents may be due to the survey mainly done in the daylight of weekdays when it is difficult to interview working male households. Regarding the level of education, around 23 percent of respondents stated a university and higher degree. The average household income is over VND7.5 million per month with the most frequent category of below VND5 million (40%), followed by VND5 million – 10 million (about 39%), and over VND10 million (nearly 21%). The higher household income level of the sample in comparison with the average household income of Mekong Delta residents (about 5.2 million per month in 2010[2]) does not show a problem in terms of a sample selection bias because the difference could be explained by the inclusion of rural households who earn lower income than urban residents in the population average.

In the contingent valuation literature, there are some ways to solve the problem of zero bids. Imber et al. (1991) treat all 'no' responses as real 'no' answers. This may result in wrong policy implications (Carson, 1991) or difficultly estimate the willingness to pay function correctly if the number of protest responses is high (Romer, 1992). Other strategy is to eliminate all zero bids, but this may cause a sample selection bias, since the remaining bids from no longer originate from a random sample of the basic population (Romer, 1992). The most common way is to identify and

Table 4. Descriptive statistics of variables in the logistic function

Variables	Description	Mean	Std. Dev.	Min.	Max.
WTP	Willingness to pay for conservation program (1 = yes, 0 = No)	0.314	0.465	0	1
Bid	Bid value (thousand VND)	58.421	35.107	10	110
Age	Age of respondents (years)	49.713	14.281	20	87
Gender	Gender of respondents (1 = Male, 0 = Female)	0.385	0.487	0	1
Graduate	Educational level of respondents (1 = Graduate or higher, 0 = otherwise)	0.232	0.423	0	1
Status	Civil status of respondents (1 = married, 0 = otherwise)	0.872	0.335	0	1
Income	Monthly household income of respondents (thousand VND)	7,547	4,073	4,500	19,500
Location	Location of respondents (1 = Can Tho, 0 = Kien Giang)	0.587	0.493	0	1
Donation	Whether respondents have made any donations (1 = yes, 0 = no)	0.702	0.458	0	1

Source: Own estimates; data appendix available from authors.

exclude protest bids from estimates of willingness to pay (Mitchell and Carson, 1989). The estimates without protest responses give the higher value of WTP than those with all 'no' responses. In this study, we use the WTP estimate without protest bids as the mean WTP and the WTP calculation for all 'no' responses as the low bound of willingness to pay.

The one of the key questions in a contingent valuation survey is whether WTP is affected by important variables suggested by economic theory, for example income, education, age, etc. or whether the coefficients of these variables have signs that are consistent with expectations. These relationships analyzed by logistic function are performed in Table 5.

Table 5. shows the results of a logistic analysis of the dichotomous choice responses to the contingent valuation questions. The model 1 is the estimates for all respondents and the model 2 shows the results after excluding protest bids. The predictive powers of models are relatively high, with nearly 76 percent in model 1, and over 74 percent in model 2. The correlation matrix across explanatory variables supports the absence of multicollinearity because there are no correlation indices that are higher than 70 percent (Khai and Yabe, 2013). The coefficients of the bid value in the two models are statistically significant and negative as expected, revealing that an increase in bid amount could reduce the 'yes' response and the existence of the WTP for conservation program. Consistently with other studies by Subade (2005) and Jianjun (2007), the coefficients of *Age* variable in the two models are statistically significant and have negative signs, implying the older respondents have more tendency to say 'no' to the WTP question. However, the residents in the sample from the age[3] of 57 are more likely to recognize the necessary of biodiversity conservation and agree to support the project since the parameters of *Age*Age* variable are significantly positive at 10 percent level. The coefficients of household *Income* are significant at the level of 1 percent. The positive sign of *Income* suggests higher income could increase the probability of 'yes' answer

Table 5. Logistic regression estimate of willingness to pay for conservation project

	Model 1 (All Respondents Included)		Model 2 (Protest Bids Excluded)	
	Coefficient	Standard Error	Coefficient	Standard Error
Bid	-0.0230***	0.004	-0.0263***	0.004
Age	-0.1133**	0.055	-0.0997*	0.058
*Age*Age*	0.0010*	0.001	0.0010*	0.001
Gender	0.3580	0.262	0.7380**	0.292
Graduate	-0.1298	0.327	-0.1577	0.359
Status	0.7818*	0.459	0.3833	0.473
Log*(Income)*	1.0777***	0.303	1.3601***	0.344
Location	0.1688	0.266	0.2740	0.288
Donation	0.7656***	0.296	0.8066**	0.317
Constant	-7.6845***	2.809	-10.0204***	3.142
Pseudo R^2	0.156		0.198	
Log likelihood	-192.230		-164.808	
Correct prediction (%)	75.956		74.359	
Observations (N)	366		312	

Notes: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively
Source: Own estimates; data appendix available from authors.

to the contingent valuation question. Regarding the motivations for conservation, the variable of *Donation* is defined as whether a respondent have ever donated for any charitable or environmental funds. The coefficients of *Donation* variable in two models are significantly positive, revealing respondents who have made any donation in the past are more willing to pay for the biodiversity conservation project. From the findings in Table 5 and applying the estimator (6), the median and mean WTP for the proposed biodiversity conservation project are calculated by utilizing the directly estimated values of the coefficients. The results of mean and median estimates of willingness to pay are presented in the Table 6.

Table 6. performs the mean WTP for all respondents is estimated to be VND16,510 with the 95% confident interval between VND-4,670 and VND29,340 while the mean WTP after excluding protest vote respondents increases up

Table 6. Willingness to pay for biodiversity conservation program

	Mean/Median of WTP	95% Confidence Interval		
		Lower Bound	Upper Bound	ASL
All respondents included	16.51	-4.64	29.34	0.053
Protest bids excluded	31.52	17.86	43.67	0.0008

Unit: thousand VND
Note: ASL: Achieved Significance Level for testing H_0: WTP<=0 vs. H_1: WTP>0
CI: Estimated by the Krinsky and Robb (1986) method
Source: Own estimates; data appendix available from authors.

to VND31,520 with the 95% confident interval between VND17,860 and VND43,670. The two mean WTPs are significantly positive at the level of 10 percent for all respondents and 1 percent for the sample with protest bids excluded.

CONCLUSION

This study tried to extend the understanding of Vietnamese households' preferences for biodiversity conservation to the context of their WTP. The mean WTP for the proposed conservation project was calculated to be approximately VND16,510 per household per month, which was about 0.32 percent of the average household income at VND5.2 million per month in the Mekong Delta region in 2010. Moreover, the study also estimated the mean WTP of VND31,520 per household per month after excluding the protest zero and scenario rejecting respondents. An aggregate welfare measure can be derived by multiplying the mean WTP by the total urban households in the Mekong Delta. According to the general statistics office (GSO, 2013), there were 4,329,100 urban people in the Mekong Delta in 2012, which were equivalent to 1,170,027 urban households with the average of 3.7 persons per urban family (Binh, 2011). The calculation discovered that Mekong Delta urban residents were willing to pay about VND19.32 billion (VND16,510 * 1,170,027 urban households) every month for biodiversity conservation. Therefore, the total value of annual urban resident's contribution is approximately VND231.81 billion ($10.97 million) which is relatively big enough for the government, policy makers and concerned people to pay more attention or give more financial invests in conserving and improving wildlife habitats and biodiversity in U Minh Thuong National Park. This total value could be the useful and trustworthy information for decision makers to allocate funds for the biodiversity conservation project while the results of this contingent valuation study could also be valuable for environmental evaluation or suggest applying this approach to the cost-benefit analysis of this project as well as other or future projects in Vietnam. In addition, the public evaluation of biodiversity conservation could help society more awareness on the important role of biodiversity, have an impact on rational behaviors or wide support of residents to improve the quantity or quality of biodiversity which benefits the present and future generation (Chen and Jim, 2010).

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ENDNOTES

1 1 USD = 21,140 VND at the date of 05/12/2013

2 The average household income of Mekong Delta residents are calculated by multiplying per capital income at 1.25 million (GSO, 2010) with the average member of 4.16 per family (Binh, 2011) in the Mekong Delta region.

3 At the minimum of Pr(Yes) function $Age_{min} = -(-0.1133)/(2*0.001) = 56.65$

APPENDIX: THE FORMAT OF CV QUESTION

Section 3: A Conservation Plan for the Protection of U Minh Thuong National Park

We will now provide you some information about U Minh Thuong in Kien Giang:

U Minh Thuong National Park is one of two large areas of peat swamp forest in Vietnam. Biodiversity conservation in this region has been assigned a national priority since it could buffer the negative effects of the Mekong River floods, recharge aquifers and provide a unique environment for many wetland species. With a total area of 8.038 ha and a buffer zone of 13.069 ha, the Park is a home of many diversified plants and animals including 243 plant, 32 mammal, 151 bird, 34 reptile, 7 amphibian, 34 fish and 181 insect species. Forty of these are listed as endangered species in the Vietnam Red Book.

Threats to Biodiversity in U Minh Thuong National Park

Although the government has declared the protected zone, U Minh Thuong is still under serious threats to biodiversity:

- Encroachment and disturbance of habitats: due to high density of local peoples, habitat area often undergoing encroachment for agriculture, aquaculture and other purposes. This activity is especially in the areas outside protected areas. Illegal encroachment causes lots of disturbance for habitat security.
- Environmental pollution caused by subsistence wastes, industrial wastes, use of insecticides, herbicides and toxic rat baits.
- Wildlife hunting and trade occurs commonly in the area. Wild animals in general and mammals in particular are hunted for household use and also for sale in urban centers.

A Conservation Plan for Biodiversity in U Minh Thuong National Park

The goal of the program is to increase the number of plants and animals in U Minh Thuong or at least keep them from declining every year. To accomplish this goal, it should be carried out the following activities:

- Rationally planning ponds, shrimp ponds and rice farming land around the buffer zone to prevent water pollution and scarcity of food.
- Planting more trees suitable for nesting and reproducing, improving ponds, swamps and grassland within and outside the buffer zone to create a food source and the better living environment for wild animals. There is also promoting tree planting in rural areas, industrial zones and urban areas to create the good habitat conditions for the biodiversity conservation.
- Enhancing the coverage of forest to protect the soil from erosion, landslides and runoff.
- Conducting education and training activities to improve the awareness of the local people to conserve biodiversity and the professional skills of the management group staff.

While the program contains many good ideas, implementing it would require money. So far, the program has not received any funding or carried out any activities. A number of international organizations do provide financial support to protect this biodiversity area. However, they usually require that counterpart funds be made available. In other words, people from region must also contribute money to protection effort. Therefore, the practical implementation of this program would require much more concerted efforts from all households.

Conservation Fund

Suppose a conservation fund for biodiversity in U Minh Thuong would be set up, all citizens could contribute to the fund. The fund could then request international organizations to provide the same amount of money or more, according to the money raised locally. The money raised by the fund would be ONLY used for the conservation activities mentioned earlier to conserve biodiversity in U Minh Thuong.

The purpose of our survey is to find out if your household would be willing to contribute ***<bid level>*** every month as a surcharge on your household water bills for the next three years. The payment is a fixed amount and it doesn't change with the volume of water used. This money would go to the conservation fund for biodiversity in U Minh Thuong.

[The recent study shows that people generally accept to contribute value more than the ability of actual contribution. This survey tries to get information on the ability of your actual contribution. So, require you to think carefully with your decision].

11. Would you be willing to pay <bid level>every month for biodiversity conservation in U Minh Thuong?
    (1) Yes (2) No

Chapter 15
Sustainable Forest Use and India's Economic Growth:
A Structural Decomposition Analysis of Direct Forest Intensity

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ABSTRACT

This paper assesses the prospect of sustainable forest management (SFM) for an emerging economy like India, where forest coverage has gone up over the last three decades in spite of population growth, rapid urbanization and fast economic growth. To assess the possibility of sustainable future growth in a globally congenial environment, the extent of ecological stress on Indian economy has been assessed by using Input-Output transaction tables and pattern of expenditure by the Government and the Private sector along with Import and Export of forestry and related products over 1993-94 to 2007-08. The change in direct forest intensity (DFI) in gross domestic product has been calculated and decomposed into effects due to material intensity, structural change and economic growth. The results reveal increasing dominance of economic growth over other effects indicating necessity of designing intervention to decouple potential future economic growth from forest resources to ensure long run sustainability.

INTRODUCTION

India is developing and by consistently maintaining a no less than 5 per cent growth of national income (www.rbi.org.in) over a reasonably long time horizon, she has been included in the club of emerging economies as a member of the BRIC[1] nations. For this growth to be socially sustainable, attention needs to be paid on the distributive policies and to be ecologically sustainable, the designing and implementation of natural resource and pollution management policies are of utmost importance. To assess the possibility of sustainable future growth in a globally congenial

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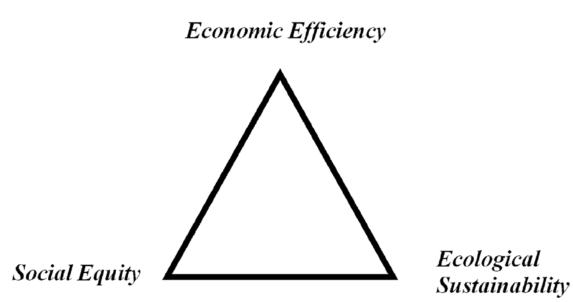
environment, one should enquire into the nature of ecological stress imparted by the present state of production and consumption at the aggregate level of the macro economy. Natural forest reserve, being a precious national stock, and having great existence value to the global society for maintaining the climatic balance is chosen as the specific sector for this assessment (Amritkar-Wani, 2009).

Destruction of natural resources began with the history of civilization, though early Man had recognized the importance of nature in their lives and was concerned for its conservation and protection. Increasing population and developing civilization have utilized more and more of natural resources, forests being one of the most affected. With the rise in population, forests are destroyed for growing food, making houses, creating roads and building cities. Forests in peripheral areas are also used up for timber by cutting down trees. Deforestation had its adverse impact on soil, water table, climate and also forest-based livelihoods. With such irresponsible use of natural resources human population has crossed over six billion and has reached the verge where exploitation surely causes irreversible damage to the ecosystem (Mukherji, 2004). Thus maintaining a balance between urban land, agricultural land and forest land to facilitate better adaptation to the impact of climate change and mitigation of its adverse influences are almost universally recognized as a fundamental issue related to *our common future*. However, environmental management demands an impeccable and accurate knowledge base of the physical interactions in nature and a constant effort to reach acceptable and tenable trade-offs between what is essential now (short-term benefits) and what is needed to secure the future (long-term benefits). In developing countries like India, where hunger and poverty are still the order of the day, the purpose of environmental management is more to secure the present. The challenge is therefore how to use the environment at increasing levels of productivity and in a sustainable manner (Aggarwal, 1992). However, this issue of sustainable development is a highly imprecise concept and is broadly defined by the Brundtland Commission in its 1987 report as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". This requires balancing the demand for natural resources with the protection of ecosystems that also contribute goods and services necessary for economic growth. The underline basis depends upon the effective and systematic integration of economic development with social equity and environmental protection (figure 1) (Condrea & Boston, 2008).

The major concern of this paper is to find out whether India's high rate of growth is coming along with a suitable forest conservation policy to make it sustainable in the long run. From the official sites it is found that the forest coverage has gone up over the last three decades in spite of population growth and rapid urbanization. However, for sustainable forest management (SFM), the direct initiative of the Forest Department needs to be complemented by rigorous demand management policy where the demand for forestry-based products from the producers should be curtailed by designing appropriate technology policy and that from the consumer should be controlled by discouraging final consumption intensive in forest materials. To be economically sustainable, the growth process needs to be decoupled from the forestry sector and the direct forest intensity

Figure 1. Three goals of sustainable forest management
Source: Condrea & Boston, 2008.



of production matrix of the economic system should reveal tendency towards substituting forest dependent products in the production basket by other non-forest dependent products. To evaluate whether any such tendency has been revealed by the Indian system over the last two decades, we have isolated the forestry and logging sector from the domestic production matrix and an analysis has been carried out in terms of input-output (IO) transaction tables. This approach is considered suitable as it is necessary here not only to determine the direct impacts of an industry but also the indirect impacts caused in the supply chain, especially when the former is likely to be very small in comparison to the latter (Mattila, Leskinen, Mäenpää, & Seppälä, 2011). Paloviita (2004) and Mattila, Leskinen, Mäenpää, & Seppälä (op. cit.) have applied the same technique for quantifying the overall sustainability impacts of forest industries in the Finnish economy and Psaltopoulos and Thomson (1993) and Roberts (1999) used the same method to analyse the role of forestry in the rural economy of Scotland to estimate the linkage effects and GDP contribution for Scottish forestry sector.

In this paper, we have discussed how I-O transaction tables can be used to assess supply chain effects and isolate the dependence of Gross Domestic Product (GDP) on the forestry and logging sector through direct, indirect and induced linkage channels by proposing a simple decomposition method that is operationally quite simple. The comprehensive linkage effect of the forestry sector and its changing profile over time has also been traced. The components of final demand have been studied and the change in direct absorption of forest based materials in the final demand vector over time has been obtained. The latter has further been decomposed into a number of effects related to material intensity, structural composition and economic growth to locate precisely the root cause of this increased demand for the forestry products. The following section briefly discusses many facets of the economy-forest interactions. Section 3 explicitly considers the nature of technical progress and forward linkages. Section 4 tries to come up with the quantitative estimate of dependence of gross domestic product on output of the forestry and logging sector. Section 5 discusses the consumption pattern of forest products of public sector and private sector along with the changing profile of imports and exports. Section 6 integrates the production side and the consumption side of the analysis by decomposing the temporal change of direct forest use into input-intensity effect, structural change (composition) effect and economic growth effect with the help of structural decomposition analysis (SDA) technique. Finally, section 7 concludes the paper by extending an overall assessment of economic sustainability and stressing the need to decouple the process of economic growth from the forestry sector to achieve that target.

MANY FACETS OF ECONOMY-FOREST INTERACTIONS

Throughout the history of human civilization forests have been a major source of natural resource products. Not merely just the green cover but forests are ecosystems which have many functions integral for our survival and sustenance. Various socio-economic functions are ascribed to them, based on the differentiated needs of the human population. From daily urban life needs to source of livelihood to home for varied habitats, forests' usefulness is almost unaccountable. The principal ways in which forests interact with economies are identified by Chopra (2006) as (i) forests as source of timber, renewable in the main but potentially depletable, usually harvested by government corporations or private loggers and used as input in wood-based industries; (ii) forests as a source of tangible non-timber forest products collected and consumed by households (e.g., fuel wood, resin, fruit, leaves, etc.) but not always bought and sold in the markets, (iii) forests as a source of less tangible forest amenities consumed directly either in the present or in the future (biodiversity related benefits), (iv) forests as a source of environmental services that benefit other productive sectors (e.g., watershed protection for downstream agriculture, forest based recreation and tourism, etc.), (v) forests as a disposal site for air pollutants that may be damaging to forest health (acid deposition); (vi) forests as a sink and source of carbon dioxide which potentially damages other sectors through global climate change (carbon sequestration) and so on. The mix of services that is available to any economy from forests depends, in addition to their biological characteristics, on the nature of economic regime within which they are exploited. Some commodities, such as timber are extracted in a regime driven, in the main, by market forces. Others such as non-timber forest products may be extracted under a variety of arrangements, the range varying from open access to common property regimes. Services such as those of water cycle augmentation and micro-climate regulation are typically available to communities as free goods (Chopra & Kumar, 2003). In fact, the importance of forest can be stemmed down from the very fact that forests need complicated systems of governance. Through deforestation, forests compete for land with agriculture and urban settlements and through the choice of institutions it competes with alternative systems of management. It is not to be treated like any other natural ecosystem like agricultural land and is not given out to private institution/ individual to do what they please (Lele, 2011).

In India, it has been claimed in many literatures that the original inhabitants were the aboriginal people whose livelihoods were based on hunting and gathering for the supply of food, fodder, fuelwood and even cosmetics (wild gems) (Ghosal, 2011). Tagore (1915) pointed out that "*in India it was in the forests that our civilization had its birth*". Vedic literature also indicates that forests were held in high esteem and 'Ashrams' (hermitages) of the sages existed within these forests. Mali, Singh, Kotwal, & Omprakash (2011) has also shown how forests play an important role in the country's economic development in terms of their contribution to GDP and employment. Again, forests are the main source of meeting food, fuel, fodder and timber requirements of the forest-dwelling communities which at present exceeds 100 million in population in the country (Sankaran, Sinha, & Madhav, 2002). Thus it is no wonder that the designing and implementation of sustainable forest management policies are also of national importance in India. Between 1990 and 2010 the area under forest land in India has gone up from 63.94 million hectares to 68.43 million hectares (http://data.gov.in/sites/default/files/FOREST_COVER_AREA_1.xls). In this paper an attempt has been made to explore the economic implications of this apparent success from the perspective of long run sustainability. One of our major contention is the position that to be sustainable, forest resources should be managed by taking into consideration both the supply as well as demand sides. The present practice in India places major responsibility on the shoulder of the Ministry of Environment and Forest, and therefore, it is more of a supply side approach. When the country is growing at a very rapid rate, the proportion of affluent people is growing and the demand for everything, including forest-based products is on the rise. So, a simultaneous demand side management is the call of the time. If both these aspects are not taken into balance, the ultimate decoupling of the forest conservation process and the economic affluence process would remain unachievable. In the following paragraphs an exploration of forest-dependence, both extent and nature, of India's GDP is presented for recent period.

FORWARD LINKAGE OF FORESTRY

As multiple-market imperfections are natural characteristics of a developing country like India, the public benefits of an investment project may diverge from the private benefits because of several reasons; inter-sectoral linkages being one of them (Jones, 1976). The nature of these inter-linkages among different sectors of the economy through technical inter-dependence gets reflected from input-output (I-O) tables and the Central Statistical Organization (CSO) of the Government of India publishes I-O tables periodically that shade light on the temporal change in this underlying structure at the disaggregated level[2]. Specifically, I-O tables provide the tools to assess structural changes in the economy, in terms of backward linkage and forward linkage between economic sectors (Reis & Rua, 2006). The analysis of these linkages has a long history, starting with the pioneering works of Rasmussen (1956), Chenery & Watanabe (1958) and Hirschman (1958) on the use of linkages to compare the difference in the productive structures of different countries. Later in 1970s, these traditional measures adapted with several new forms are put forward by Laumas (1976), Jones (op. cit.), etc. More recently, Cella (1984), Sonis, Guilhoto, Hewings, & Martins (1995), Dietzenbacher & Van der Linden (1997) and others have suggested a few alternative methods to isolate the contribution of any particular sector on the national income known as the hypothesis extraction method (Andreosso & Yue, 2004).

Here the economic importance of forestry in domestic production has been analyzed by studying both the *technical progress* and *forward linkage* chain of the forestry & logging sector; while the former has been done in terms of Chenery-Watanabe method the latter is accomplished by using Jones (op. cit.) method based on output inverse matrix and a comparison of the result has been made with Rasmussen's (op. cit.) method of input-inverse matrix based assessment.

Considering an economy with n number of inter-dependent sectors and a final consumption commitment, the input-output relation can be expressed as: $X = AX + C$ where $X = (X_1, X_2, ..., X_n)'$, the vector of output, $A = \left[a_{ij} \right]$ the matrix of input-output coefficients where a_{ij} represents the amount of X_i used in the unit production of X_j and $C = (C_1, C_2, ..., C_n)'$, the final consumption vector.

Technical Progress

Generally, the technical progress is said to occur when either the same amount of inputs produces more output or the same amount of output is produced by using less inputs. Dholakia, Agarwalla, Bazaz, & Agarwal (2009) suggested a number of situations that may lead to such technical progress even in the absence of change in relative prices of inputs and/or output: (a) quality of inputs may change, (b) quality of output may change, (c) new inputs may be introduced, (d) some inputs may become obsolete and be withdrawn from the use in production, (e) new production process and technique may be discovered and used, (f) better organization of production processes may increase input-use efficiency and (g) composition of output may change.

To assess the technical change, the corresponding coefficients of I-O matrices for any two successive periods have been compared by following Chenery-Watanabe (C-W) method that can be represented as follows:

$$\gamma^{t_1 t_0} = \left[\sum_j \left| a_{ij}^{t_1} - a_{ij}^{t_0} \right| \Big/ \frac{1}{2} \sum_j \left(a_{ij}^{t_1} + a_{ij}^{t_0} \right) \right]$$

where t_1 and t_0 represents two time points and $\boldsymbol{a}_{ij}$ represents the coefficient in i-th row and j-th column of matrix A. For Forestry & Logging sector $\gamma^{98-99,93-94} = 0.1845$, $\gamma^{03-04,98-99} = 0.6544$

and $\gamma^{07-08,03-04} = 0.5768$ and $\gamma^{07-08,93-94} = 0.9834$, indicating a marginal improvement in technical coefficients over these two decades.

This implies that these sectors are gradually developing dependence on other secondary sectors. However, the implication of this technological change needs to be interpreted with some social caution. A key determinant of natural resource management is technology and as forest-product related technologies become more productive in an economic sense, forests are more likely to be overexploited. Technological progress accelerates economic growth, but relatively slow-growing natural resource systems, like forests, come under greater pressure from the demands of economic efficiency (Harris, 2006).

Forward Linkages

This inter-industry interdependence reveals two types of linkages: backward and forward. If sector *i* increases its output, then there is increased demand on the sectors whose products are used as inputs to production in *i*. This demand relationship is referred to as backward linkage. Increased output in sector *i* also means that additional amounts of product *i* are available to be used as inputs to production in the other sectors. This supply relationship is referred to as forward linkage (Reis & Rua, op. cit.). Thus, the backward linkage is *input provision* or input demand derived from the production activities of the *i*-th sector (column sum) and the forward linkage refers to *output utilization*, i.e., how the output of the *i*-th sector is being used as input by all other sectors of the economy (row sum). For our purpose the calculation of forward linkage will be more relevant as we are interested in knowing the increase in induced demand for the product of the forestry & logging sector by the rest of the economy following a change in both the production and consumption matrices over the last two decades. This exercise will help us to quantify the absorption of the products of forestry and logging sector in the production of other sectors through direct and indirect linkages and will ascertain the technological dependence of the economy on the forest based products as inputs.

Chenery-Watanabe (op. cit.) proposed the use of row sum of the input-coefficient matrix ***A*** as a measure of forward linkage. I.e., $FL^i_{CW} = \sum_j a_{ij}$ is the forward linkage of sector *i*. However, this can at the best capture the direct impact and not the indirect impact imparted through the subsequent stages of interdependence. So, Rasmussen (op. cit.) proposed to take the row sum of the input inverse matrix $Z = (I - A)^{-1}$ where $(I - A)^{-1} = I + A + A^2 + A^3 + ...$ so that both direct and indirect impact would be taken into account. I.e., $FL^i_R = \sum_j z_{ij}$. Jones (op.cit.) criticized this entire approach of input-coefficient [$\boldsymbol{A}$] matrix or input inverse [$(\boldsymbol{I} - \boldsymbol{A})^{-1}$] matrix based assessment of forward linkage and suggested an alternative method as more comprehensive one which is based on output coefficient matrix [$\boldsymbol{B}$] and output inverse matrix [$(\boldsymbol{I} - \boldsymbol{B})^{-1}$]. The matrix ***B*** has technical output coefficients as its elements, where $\boldsymbol{b}_{ij}$'s are defined as intermediate sales of sector ***i*** to sector ***j*** as a share of total sales of sector ***j*** including final demand. To capture this final demand part one has to add the gross value added $\left[V_j\right]$ with the total intermediate sales $\left[\sum_i x_{ij}\right] \rightarrow X_j = \sum_i x_{ij} + V_j$ (Table 1).

The methodology proposed by Jones (op.cit.) can be summarized as follows:

Define an $(n\,x\,n)$ diagonal matrix ***/X/*** by taking the elements of vector ***X*** as diagonal elements and get the intermediate input flow matrix as $\boldsymbol{F} = \boldsymbol{A}/\boldsymbol{X}/$; then, the output coefficient matrix would be $\boldsymbol{B} = /\boldsymbol{X}/^{-1}\boldsymbol{F}$ and the output inverse matrix would be $\boldsymbol{W} = (\boldsymbol{I} - \boldsymbol{B})^{-1}$. The $\boldsymbol{w}_{ij}$ element of ***W*** is the increase in output of the ***j***-th industry required to utilize the increased output brought about by a unit of

Table 1. Input-output transaction table

	Industry 1 Industry 2	Final Demand	Total Domestic Products
Industry 1 Industry 2	x_{11} x_{12} x_{21} x_{22}	F_1 F_2	X_1 X_2
Gross Value Added	V_1 V_2		
Total Domestic Products	X_1 X_2		

Source: Author's understanding

primary input into the ***i***-th industry. Hence, the forward linkage of sector *i* would be the ***i***-th row sum of ***W***,

$$FL_J^i = \sum_j w_{ij} .$$

It is important to indicate the difference between the comprehensive effect captured through the input inverse matrix ***Z*** and the output inverse matrix ***W***. ***Z*** gives the effect of expansion on suppliers, while ***W*** gives the impact on user industries. The ***Z*** matrix starts at the end of the production process, with an increase in final demand, and traces the effect backward through the system. The ***W*** matrix starts at the beginning of the production process, with an increase in primary inputs and traces the effect forward through the system. If for any two industries ***i*** and ***k***, $\boldsymbol{FL_J^i > FL_J^k}$, then that implies industry ***i*** is more basic than industry ***k*** in the sense that a succession of user industries processes its output rather than just one or two limited ones. Following alternative methods, table 2 presents the temporal profile of forward linkages of forestry & logging and its associated sectors in India.

Both by Rasmussen and Jones measure all the 4 forestry and related sectors have comprehensive forward linkage values greater than unity; so according to Reis & Rua (op. cit.), these sectors are the key sectors of the economy. For forestry and logging sector the input inverse based value is greater than the output inverse based value indicating the effect of increase in this input on suppliers is greater than that on the users; in contrary, for all other derived industries like wooden furniture & fixture, wood & wood products and paper, paper products & newsprint the impact on user industries dominate. The impact is the highest on the paper industry followed by wood products which generally exceeds 3. The forest conservation policies adopted since the late 80s have succeeded in controlling the dependence of the user industries on this sector directly, however, that of the associated sectors are highly substantial and deserve targeted policy focus.

Table 2. Forward Linkage of Forestry: 1993-94 to 2007-08

Sectors	Year	FL_{CW}	FL_R	FL_J
Forestry and logging	1993-94	0.56	1.98	1.76
	1998-99	0.45	1.80	1.72
	2003-04	0.52	1.91	1.82
	2007-08	0.64	2.17	1.90
Furniture and fixtures-wooden	1993-94	0.08	1.15	1.73
	1998-99	0.10	1.19	1.62
	2003-04	0.04	1.06	1.31
	2007-08	0.15	1.30	1.50
Wood and wood products	1993-94	0.63	2.02	2.31
	1998-99	0.72	2.15	2.50
	2003-04	0.40	1.73	3.95
	2007-08	0.26	1.49	2.30
Paper, paper prods. and newsprint	1993-94	0.94	3.00	3.28
	1998-99	0.99	2.99	3.21
	2003-04	0.91	2.96	3.47
	2007-08	0.85	2.78	3.08

Source: Author's calculation from CSO data

FORESTRY AND LOGGING: TOTAL CONTRIBUTION TO GDP

To assess the importance of Forestry & Logging sector in the national economy we have to estimate the direct, indirect and induced contribution of the sector in GDP. The direct contribution is available in the break-up of the gross domestic product by the 'industry of origin'; the indirect contribution is assessed in terms of the contribution of directly forest dependent sectors like wooden furniture & fixture, wood & wood products and paper, paper products and newsprints in GDP through input-output channels of inter-sectoral interdependence. To estimate this indirect contribution, the forest and related sectors are dropped from the I-O table and the final demand vector (GDP without forestry) is calculated. Difference between this adjusted GDP and the actual GDP gives the indirect contribution of forestry. Finally, the induced contribution is estimated by isolating the contribution of other non-wood related sectors in GDP who are connected with forestry & logging through forward linkage only by applying the same technique proposed for isolating indirect effect (Figure 2, Table 8 & Table 3 presents this decomposition).

Let us consider the same *(n x n)* system $X = AX + C$ where the n sectors can further be decomposed into one sector (Forestry & Logging), which is of original concern, next *(k-1)* sectors that are indirectly related, next *(m-k)* sectors with induced dependence and the remaining *(n-m)* sectors as unrelated to the first sector. Then the contribution of each group in the final consumption ***C*** (the GDP) can be isolated by applying the following method[3]:

$$(I - A)X = C, \text{ or, } BX = C, \text{ where}$$

$$\begin{bmatrix} B_{k\times k} & B_{k\times(n-k)} \\ B_{(n-k)\times k} & B_{(n-k)\times(n-k)} \end{bmatrix} \begin{bmatrix} X_k \\ X_{n-k} \end{bmatrix} = \begin{bmatrix} C_k \\ C_{n-k} \end{bmatrix}$$

or,

$$\begin{bmatrix} B_{k\times k}X_k + B_{k\times(n-k)}X_{n-k} \\ B_{(n-k)\times k}X_k + B_{(n-k)\times(n-k)}X_{n-k} \end{bmatrix} = \begin{bmatrix} C_k \\ C_{n-k} \end{bmatrix}$$

So, contribution of first *k*-sectors in GDP could be isolated by taking out the contribution

Figure 2. Direct, Indirect and Induced Contribution of Forestry & Logging Sector in GDP
Source: Author's understanding

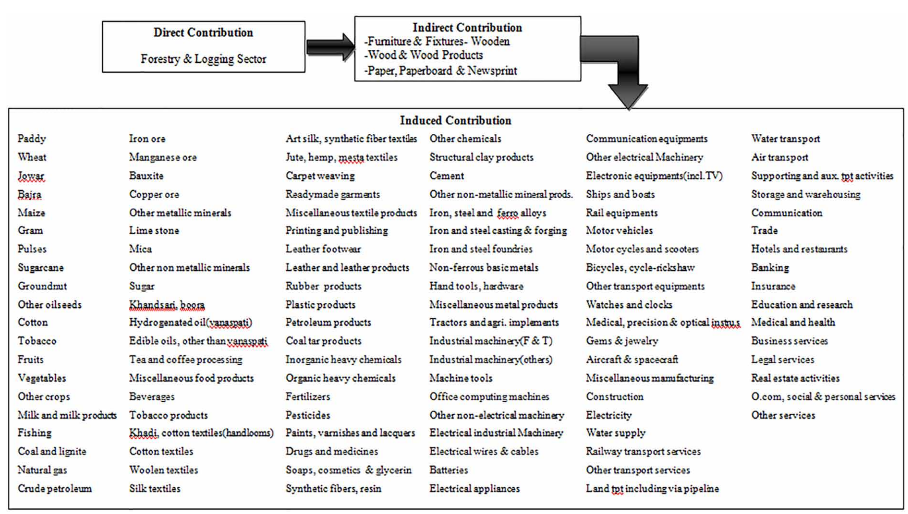


Table 3. Round-wise frequency of forest dependency for non-wood-related sectors

Frequency	Number of Sectors
4	97
3	1
2	17
1	1

Source: Author's calculation from CSO data

of remaining *(n-k)* sectors from the vector C. The forestry unrelated part of the GDP will be ..:

$$B_{(n-k)\times(n-k)}X_{n-k} = C_{n-k} - B_{(n-k)\times k}X_k = D_{n-k}$$

The aggregate value of this contribution would be $\left[e'_{(n-k)}D_{n-k}\right]$, where $e'_{(n-k)}$ is a sum-vector of order *(n-k)*. When this part is subtracted from the total GDP, the contribution of the first k-sectors can be obtained as: $\left[e'_nC - e'_{(n-k)}D_{n-k}\right]$. Thus,

The direct contribution of Forestry & Logging (sector 1) in GDP is C_1;

The indirect contribution in GDP through next (k-1) sectors is $\left[e'_nC - e'_{(n-k)}D_{n-k} - C_1\right]$;

The induced contribution through next (m-k) sectors: $\left[e'_nC - e'_{n-m}D_{n-m} - e'_{n-k}D_{n-k}\right]$ as $\boldsymbol{C_1}$ is already contained in the third term.

So, the gross contribution of Forestry & Logging through direct and indirect channels of technological dependence would come up to:

$$C_1 + \left[e'_nC - e'_{(n-k)}D_{n-k} - C_1\right] + \left[e'_nC - e'_{n-m}D_{n-m} - e'_{n-k}D_{n-k}\right]$$

$$= \left[2\left(e'_nC - e'_{n-k}D_{n-k}\right) - e'_{n-m}D_{n-m}\right];$$

Table 3 presents the number of sectors for each I-O matrix which are connected with the Forestry & Logging sector through induced channels. In 1993-94 and 1998-99, the total number of sectors was 115 and in 2003-04 and 2007-08, that has gone up to 130. Three wood-related sectors are already identified as indirectly dependent on Forestry & Logging. Out of the remaining 111 (and 126) sectors, 97 sectors show induced dependence for all four years and another 1 sector for three times, 17 for two times and so on. Thus, more than 80 per cent of GDP has some induced linkage with the Forestry & Logging sector and this dependence is temporally stable without any sign of decline over the last two decades.

Table 4 shows the direct, indirect and induced contribution of the Forestry sector on India's GDP over time. Though the direct contribution of Forestry sector in GDP never exceeded 2 percent, it has gone up from 1.05 per cent in 1993-94 to 1.72 per cent in 2007-08, by which time the size of the economy also increased nearly 2.64 times, i.e., from Rs.2.31 trillion to Rs.8.77 trillion in 1993-94 prices. So, there is no compelling reason to believe that a serious and comprehensive forest conservation policy is being followed by

Table 4. Total contribution (%) of forestry and logging sector in India's GDP

Year	Direct Contribution	Indirect Contribution	Induced Contribution	Total
1993-94	1.05	4.51	80.53	86.09
1998-99	1.07	3.54	82.35	86.96
2003-04	0.65	3.73	82.60	86.92
2007-08	1.72	3.19	82.78	87.69

Source: Author's calculation from CSO Data the Government. Of course, there is a marginal decline noted in the share of indirect contribution whereas the induced contribution is more or less stagnant; in all, the total presence of the sector is highly visible at around 87 percent. Thus forestry and logging is not only a basic industry in our domestic economy it is an industry with very high presence in our production structure through integrated input-output flows.

To supplement this production based analysis, one needs to study the pattern of expenditure over time by government and other private agents on the products of forestry sector and the role played by the domestic and foreign sources (imports as well as exports) to meet this demand. The following section will report that analysis.

PATTERN OF CONSUMPTION EXPENDITURE ON FOREST PRODUCTS

For the Forestry & Logging sector, the government consumption in 1993-94 prices has gone down from Rs.11.0 million to Rs.1.9 million over the period 1993-94 to 2007-08, whereas over the same period the private consumption expenditure on the same sector has increased from Rs.73335.3 million (i.e., Rs.73.3 billion) to Rs.212216.4 million (i.e., Rs.212.2 billion), export from Rs.3.4 billion to Rs.6.1 billion and import from Rs.5.0 billion to Rs.23.9 billion (Table 5). Though the government is trying to economize on the use of forest products in railway sleepers, construction industry

Table 5. Pattern of expenditure on forest related products (Rs. in million at 1993-94 prices)

Sector	Expenditure Type	1993-94	1998-99	2003-04	2007-08
Forestry & Logging	GFCE	11.0	---	2.6	1.9
	PFCE	73335.3	87074.6	106050.7	212216.4
	Export	3383.0	7834.3	6262.0	6054.3
	Import	5030.1	13379.4	18661.2	23907.4
Wooden Furniture & Fixture	GFCE	969.0	1032.8	2338.4	11185.6
	PFCE	10144.9	26950.8	20322.3	64375.2
	Export	77.3	267.7	1377.6	4654.2
	Import	---	39.4	218.4	1415.3
Wood & Wood Products	GFCE	---	---	4.4	2.5
	PFCE	2112.6	5996.7	2086.9	25651.9
	Export	1761.7	1138.2	1071.3	1738.4
	Import	328.3	1279.5	6729.1	4529.8
Paper, Paper Products & Newsprints	GFCE	2961.8	5440.3	4543.4	20166.4
	PFCE	9082.6	15592.3	15180.3	32036.2
	Export	3276.6	16129.5	6048.0	8626.0
	Import	17906.3	40711.4	27510.7	49225.5

Source: Collated from different CSO commodity x industry transaction tables (particularly in the public sector), furniture and panelling, mine-pit props, paper and paper board etc. (National Forest Policy, 1988), the attempted conservation strategies are getting jeopardized by the unbound increase in private consumption where in the dearth of domestic supply import from abroad is serving as a supplementary source. The pattern of consumption for Wood & Wood products is also suggesting a similar story. By 2007-08, though the government consumption is as low as Rs.2.5 million and the exports are also steady around Rs.1750.0 million (i.e., 1.75 billion), the private consumption and import are increasing exponentially, the former from Rs.2.1 billion to Rs.25.7 billion and the latter from Rs.0.3 billion to Rs.4.5 billion, suggesting a tendency for unleashed consumption.

For Wooden Furniture & Fixture, an increasing trend is observed for all components like government consumption, private consumption, export and import and in each case the change is quite substantial. However, the most noticeable change is observed in case of Paper, Paper products & Newsprints, where the value of government expenditure is the highest among all these four sectors. For all these forestry related sectors, the growth of private consumption surpassed that of government consumption and the growth of import surpassed that of export. Is this import required to support domestic production? This query has prompted us to estimate the import coefficient matrix which will show the dependence of our production matrix on the imported inputs of the forestry and logging related sectors.

Import Coefficient Matrix

In the original Input-Output transaction relation $X = AX + C$, the final consumption vector can be decomposed into domestic final demand (***Y***) and export (***E***). If we assume that the exports are net of imports, since all $\boldsymbol{a_{ij}}$'s may contain imported inputs, hence the import coefficients by row can be defined as

$$m_i = \frac{M_i}{\sum_j x_{ij} + Y_i}.$$

So, $\boldsymbol{m_i}$ represents the ratio of imports in product ***i*** within total domestic demands, or ratios of dependence on imports and ***(1-m_i)*** represents self-sufficiency ratios. The diagonal matrix ***/M/*** can be defined as the Import Coefficient Matrix by taking $\boldsymbol{m_i}$'s as diagonal elements.

The import coefficients for the relevant input-output matrices have been generated and the result is given in table 6. The requirement of imported input for paper, paper products & newsprint always dominates, though the magnitude of import coefficient is more or less stable except for the year 1998-99. For wooden furniture & fixture the

Table 6. Import coefficients

Name of Products	Import Coefficient			
	1993-94	1998-99	2003-04	2007-08
Forestry & Logging	0.0437	0.0959	0.1214	0.0515
The Furniture & Fixtures- Wooden	0.0000	0.0007	0.0048	0.0076
Wood & Wood Products	0.0047	0.0123	0.1249	0.0318
Paper, paper prods. & newsprint	0.1690	0.2961	0.1735	0.1527

Source: Calculated by author from different CSO commodity x industry transaction tables coefficient is increasing steadily over time and for both forestry & logging and wood & wood products the increasing tendency has suddenly been checked in 2007-08. So, the part of import absorbed in the production matrix alone cannot explain the rapidly widening gap between import and export of forestry based products. Increase in final consumption demand must have some major role to play in this regard. It is disturbing to observe that over time the net import of forestry & related products are sharply increasing indicating more final demand of the sector. If the government discourage use of forest produces as intermediate as well as final products and the affording class imports these as lifestyle products from abroad, then we are not culturally conserving the scarce resource but only draining from the other countries with weaker environmental regulations to satisfy our own requirements (Bit & Banerjee, 2014).

Economic growth is measured in monetary terms whereas sustainable growth is assessed in terms of conservation of the material balance. So, for sustainable management of forest it would be interesting to isolate the contribution of different drivers like the change in (i) the technique of production, (ii) the composition of the economic system and (iii) the scale of the Indian economy in explaining this exponential increase in final consumption of wood based products and to investigate the ecological pressure imparted on the physical system of the country in terms of the change in the magnitude of direct forest input (DFI) used. That is carried out in terms of a structural decomposition analysis (SDA) in the following section.

DIRECT FOREST INTENSITY AND SDA

Structural decomposition analysis (SDA) is generally applied to break down the growth in some variable into the change in its determinants (Dietzenbacher & Los, 1998) and has been widely used to assess the environmental stress in terms of material balance for a number of rapidly growing economies. In fact, one way to study the changes in forest stocks is by switching the focus of analysis from the forestry assets to the wood flows that are supplied to the economy. If that is done, then the typical I-O system can be used to decompose the change in total use of forest materials into different component effects known as the drivers. Among others, Haan (2001) used it to analyze the impact of pollution in the Netherlands; Lenzen (2003) used it in the Australian context, Muñoz & Hubacek (2008) applied SDA to unearth the implication of Chile's economic growth, and recently the UNEP used this technique in Nairobi to assess the role of forest for the Kenyan economy (2012). A similar decomposition has been attempted in this section for the rapidly growing economy of India.

The Method

In a particular time period (t) the wood (M) used by the economy can be written as follows: $M_t = m^{q'} \times (I - A)^{-1} Y_t$, where $M_{t(1x1)}$ is the amount of wood used by the economic system at time t, $m^{q'}_{(1xn)}$ represents the transposed vector of direct wood intensities, $(I - A)^{-1}$ is the well-known Leontief inverse $L_{(nxn)}$ and $Y_{(nx1)}$ is the final demand[4]. So, the equation expresses total (direct plus indirect) amount of wood required (M) to produce any final demand vector Y, given direct material intensity ($m^{q'}$) and the economic structure (L).

To identify the drivers of the change in M over two different points in time (say, t_0 and t_1) the following decomposition can be proposed:

$$\Delta M = (M_1 - M_0) = (m_1^{q'} \times L_1 \times Y_1) - (m_0^{q'} \times L_0 \times Y_0);$$

The difference between periods (1) and (0) can be generated by different possible combinations of the decomposition under study and there is no a priori rationale to rank them in order of preference (Dietzenbacher & Los, op. cit.). So, the convention is to take the simple average of two polar decompositions.

The first polar decomposition begins with the final year and gives:

$$\Delta M = \Delta m^{q'} \times L_1 \times Y_1 + m_0^{q'} \times \Delta L \times Y_1 + m_0^{q'} \times L_0 \times \Delta Y;$$

The second polar decomposition begins with the base year to give:

$$\Delta M = \Delta m^{q'} \times L_0 \times Y_0 + m_1^{q'} \times \Delta L \times Y_0 + m_1^{q'} \times L_1 \times \Delta Y;$$

The average solution would be the most reliable one as it would approximate the average of all decompositions (3! in all) possible in this case (Mukhopadhyay & Forssell, 2005).

$$\Delta M = \tfrac{1}{2}\left[\begin{array}{l}\Delta m^{q'}(L_1 Y_1 + L_0 Y_0) + \\ \Delta L(m_0^{q'} Y_1 + m_1^{q'} Y_0) + \Delta Y(m_0^{q'} L_0 + m_1^{q'} L_1)\end{array}\right]$$

where $\Delta m^{q'}$ captures the change of wood intensity of unit output or the material intensity, i.e., the efficiency gain through technological change, ΔL measures the change in the commodity input structure, i.e., changes between and within the sectors and ΔY measures the change in the volume of final demand or GDP. Thus, the total change is decomposed into (i) material intensity effect, (ii) structural change effect and (iii) economic growth effect.

India's Situation

It is interesting to note that the change in GDP and that of the direct material use of wood products in India is maintaining a steady ratio of 0.03 for all the periods under consideration with a marginal reduction for 1999-2004. That indicates an increasing ecological stress on the system as India is joining the club of the emerging economies. If the annual average value is calculated for ΔM, then it has gone up nearly seven-fold between 1994-99 and 2004-08. From the SDA values (Table 7) it is clear that growth effect is the main economic driver of forest resource use whereas the structure effect reflecting on changes in the intermediate production structure of the Indian economy and the material intensity effect representing the technical efficiency gain are not performing with consistency and stability across phases. So, the efforts here are not culminating into a strong enough force to de-link the attainment of high economic growth from excess use of forest resources.

Table 7. Contribution of different drivers to change in forest-use in India (Rs. in billion at 1993-94 prices) [5]

Reference Period*	Change in Forest Use (ΔM)	Material Intensity Effect ($\Delta m^{q'}$)	Structural Change Effect (ΔL)	Economic Growth Effect (ΔY)
1994-1999	392.67	-10.08	-8.13	410.88
1999-2004	281.05	-168.96	38.90	411.11
2004-2007	1415.52	256.44	-8.78	1167.86
1994-2007	2089.24	-116.41	827.21	2122.92

Source: Calculated by author from different CSO commodity x industry transaction tables
Note: *Year 1993-94 has been reported as 1994 and so on.

CONCLUSION

In this paper, an attempt has been made to assess the prospect of sustainable forest management for an emerging economy, like India, where the area under forest coverage has gone up marginally over the last three decades in spite of population growth and rapid urbanization. Input-output analysis shows that forestry and logging sector and its associates are all important key sectors of the Indian economy as the values of forward linkage are always greater than unity. The precise magnitude of these values indicate that though the forest conservation policies adopted since the late 80s have succeeded in controlling the dependence of the direct-user industries on this sector, that of the associated sectors are highly significant and deserve targeted policy focus. The share of government consumption in the total output of the forestry sector has gone down and a conscious attempt towards conservation is noted from the supply side. However, with rapid income growth, given the high demand elasticity of the wood based products, there is sharply growing gap between demand and supply. India's per capita consumption of paper and paperboard is less than 10kg (compared with 71kg/capita in China and 236kg/capita in the US), however, demand has been growing rapidly and consumption of recovered paper, wood pulp and non-wood pulp have nearly doubled over the past decade (FAO, 2010). This phenomenon again indicates the presence of strong inter-sectoral linkages that makes the indirect and induced demand for forestry substantially high in our analysis. In fact, even in 2007-08, more than 87% of India's GDP is found to be linked with the forestry based sectors through some indirect and/or induced channels.

The import of forestry based products is also increasing over time and it is found to be mainly for private consumption purposes. Patil, Manjunatha, & Chandrakanth (2013) considers this import dependent growth in consumption as off-shoot of institutional reforms like liberalization and forest conservation. If the government discourage use of forest produces as intermediate input as well as final products and the affording class imports these as lifestyle products from abroad, then we are not culturally conserving the scarce resource. Another study has been taken up by Bit & Banerjee (*op. cit.*) to identify the major importers who are supplying forestry based products to bridge this consumption-production gap. Since forest resource is very active agent in absorbing carbon-dioxide and supplying fresh oxygen to combat global warming, India's unleashed demand (met through import from outside) will eventually have its impact on reduced wood stock of the other countries and the consequent pressure on the climatic cycle of the planet will not only thwart the process of economic development but the mere sustainable existence of the system will be questioned.

A structural decomposition analysis has been presented at the end to integrate this economic system with the physical system to isolate the relative importance of different drivers like gain in technological efficiency, changes in intermediate production structure and economic growth in exerting or relaxing the pressure on the material balance with its long term implications for ecologically acceptable development. The results reveal increasing dominance of economic growth over other effects indicating necessity of designing intervention to decouple potential future economic growth from forest resources to ensure long run sustainability. To achieve this end a more comprehensive policy package needs to be designed. If no restriction is imposed from the demand-side, mere supply-side management would be inadequate to ensure sustainable forest use for this slow-growing renewable resource which has enormous potential for climate balancing. For this one needs to combine economic vision with political will.

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ENDNOTES

1. BRIC stands for Brazil-Russia-India-China;
2. The I-O tables are in the form of square matrices showing in each row the disposal (use) of output of a sector as input used in different sectors (intermediate use) and for final use in the economy during the year. They cover all sectors of the economy and their subsectors.
3. Refer Table 8 for the detailed matrix break-up.
4. As an example of the input-output transaction matrix used for the SDA, the constructed absorption matrix for the year 1993-94 is reported in appendix (Table 9 and 10).
5. The detailed calculation is given in appendix (Table 12).
6. For explanations see Table 11
7. For explanations see Table 11

APPENDIX 1: LIST OF ABBREVIATIONS

BRIC: Brazil-Russia-India-China
CSO: Central Statistical Organization
C-W: Chenery-Watanabe
DFI: Direct Forest Intensity
GDP: Gross Domestic Product
GFCE: Government Final Consumption Expenditure
IO: Input-Output
PFCE: Private Final Consumption Expenditure
SDA: Structural Decomposition Analysis
SFM: Sustainable Forest Management

APPENDIX 2

Table 8. Method of Decomposition

Matrix Break-up	Matrix Break-up		k				n-k					
	Sector Code		21	50	51	52	1	……	114	10	……	115
	Sector Code	INDUSTRY COMMODITY	Forestry and logging	Furniture and fixtures-wooden	Wood and wood products	Paper, paper prods. & newsprint	Paddy	……	Other services	Jute	……	Public administration
k	21	Forestry and logging	b_{11} DIRECT	$B_{k \times k}$ (DIRECT + INDIRECT)			(INDUCED) $B_{k \times (n-k)}$					
	50	Furniture and fixtures-wooden										
	51	Wood and wood products										
	52	Paper, paper prods. & newsprint										
n-k	1	Paddy	$B_{(n-k) \times k}$ (INDUCED)				$B_{(n-k) \times (n-k)}$ (UNRELATED)					
	……	……										
	114	Other services										
	10	Jute										
	……	……										
	115	Public administration										

Source: Author's Understanding

Table 9. Input Output Transactions (Commodity X Industry) Table, 1993-94

	Absorption Matrix													
Sector Code[6]	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**
I	4677474	160	399	0	2571158	977572	3661	16220	322187	23151	220147	16228	793860	0
II	140	4997		0	62095	8993	214852	38066	31995	10934	40120	0	10996	0
III	0		21302	0	73881	0	0	0	60	14147		0	7410	0
IV	37	0	0	41902	37993	41003	2070	53526	1888780	945492	521978	947887	80412	0
V	162615	0	4699	0	380202	5474	228	2458	19855	894	0	0	169988	5
VI	51433	3396	25751	5716	32814	1736476	5579	16619	100791	211877	16901	925	330838	54344
VII	1731	59	5724	7401	28489	18682	70279	17439	30852	123720	299343	1300	7981	71256
VIII	4447	3068	203	3258	60040	27488	4396	412313	196077	65487	7497	17789	98140	179029
IX	1452608	9022	26408	125441	167242	772262	31383	115698	2756423	1143565	442697	42244	1204201	51675
X	59626	9925	38518	189228	111797	137411	23926	45366	226538	6671560	2280563	162283	901817	163273
XI	164223	30183		28120	14731	18787	4431	4630	21166	48528	83359	52224	289264	240283
XII	407358	728	1238	117752	69655	304932	13412	74619	424118	858883	163940	1170204	802070	259511
XIII	818598	25666	17157	70448	389702	809564	43011	146570	673706	1248326	875144	442459	816811	521572
XIV	831235	3757	15031	37638	592422	790780	53289	113651	739136	1186358	934341	294580	567891	160153
XV	189521	4675	3330	43353	112689	175816	22530	36330	224621	747579	244324	94439	683916	822218
XVI	0	9000	0	0	0	0	0	0	0	0	0	0	120477	0
XVII	18917	4619	7050	40276	128425	183831	11530	12102	64768	549194	90717	42197	308665	754359
XVIII	0			0	0	0	0	0	0	0		0	0	0
Total Inputs at Factor Cost	8839963	109254	166809	710533	4833334	6009068	504578	1105609	7721075	13849695	6221070	3284757	7194738	3277678
Net Indirect Tax	-1109598	4256	7413	53202	196787	268708	22048	86133	543264	1269305	329828	142660	1063175	114846
Total Inputs at Purchaser's Price	7730366	113510	174222	763734	5030121	6277776	526626	1191741	8264339	15119000	6550898	3427417	8257912	3392525
Gross Value Added	22498281	1021590	911585	1970155	1354141	2335561	480737	489155	2380273	5442053	4043302	1896890	6280094	10618427
GROSS Value of Output	**30228647**	**1135100**	**1085807**	**2733889**	**6384262**	**8613337**	**1007363**	**1680896**	**10644612**	**20561053**	**10594200**	**5324307**	**14538006**	**14010952**

Table 10. Input Output Transactions (Commodity X Industry) Table, 1993-94

Absorption Matrix													
Sector Code[7]	**XV**	**XVI**	**XVII**	**XVIII**	**Total IIUSE**	**PFCE**	**GFCE**	**GFCF**	**CIS**	**EXP**	**Less IMP**	**Total F.Use**	**Total Output**
I	0	38503	29169	0	9689890	19780601	140125	129401	149265	364593	180785	20383199	**30073089**
II	0	0			423189	733353	110		-5081	33830	50301	711911	**1135100**
III	0	0			116799	771792	398		-854	172126	2150	941312	**1058110**
IV	0	0	513	0	4561591	21204	3396	0	-54830	133610	1931082	-1827702	**2733889**
V	0	134	0	0	746551	5032214	10498	0	118611	468260	126385	5503197	**6249749**
VI	1388	1922	6158	0	2602929	3605418	3360	232418	69006	1529225	224878	5214548	**7817477**
VII	1870	8566	13510	0	708202	122575	9690	48774	28195	18390	3283	224342	**932545**
VIII	30089	24579	27946	0	1161846	462100	85834	0	59612	42422	232802	417167	**1579013**
IX	6402	525642	14719	0	8887632	1505236	453386	114700	403289	719457	1977422	1218646	**10106278**
X	37211	27093	350190	0	11436324	1516763	678555	8142541	-899014	2264443	4004580	7698708	**19135032**
XI	297466	83568	41135		1422098		533855	8777070				9310925	**10733022**
XII	47546	41857	27797	0	4785620	507759	179301	0	0	808	0	687868	**5473488**
XIII	112985	148801	63499	0	7224019	5443977	375658	475904	0	1118337	99889	7313987	**14538006**
XIV	8680	155804	67693	0	6552441	5815184	172476	759073	0	1217266	0	7964000	**14516441**
XV	374893	17158	175296	0	3972686	5310936	347721	0	0	43819	69116	5633359	**9606045**
XVI	0	89316	0	0	218794	2499046	1928500	0	0	0	0	4427546	**4646340**
XVII	93389	67007	68245		2445292	2784813	230075			682197	774029	2923056	**5368348**
XVIII	0	0			0		4309400					4309400	**4309400**
Total Inputs at Factor Cost	1011919	1229951	885870	0	66955901	55912970	9462339	18679881	-131800	8808782	9676702	83055470	**150011372**
Net Indirect Tax	13619	43295	98830		3147770	3442792	161661	1089819		-54543		4639729	**7787499**
Total Inputs at Purchaser's Price	1025538	1273246	984700	0	70103671								
Gross Value Added	8580508	3373094	1922455	4309400	79907700								**79907700**
GROSS Value of Output	**9606045**	**4646340**	**2907155**	**4309400**	**150011371**	**59355762**	**9624000.1**	**19769700**	**-131800**	**8754239.4**	**9676702.2**	**87695199**	

Note: PFCE: Private Final Consumption Expenditure, GFCE: Government Final Consumption Expenditure, GFCF: Gross Fixed Capital Formation, CIS: Change in Stocks, EXP: Export, IMP: Import, F.Use: Final Use.

Table 11. Sector Classification for Table 9 and Table 10

Sector Codes	Sector Classification	Sector Codes According to Table A.1
I	Agriculture	1 - 16
II	Forestry and logging	-
III	Fishing	-
IV	Mining and Quarrying	18 - 28
V	Food Manufacturing	29 - 36
VI	Textile & Clothing and Leather & Footware	37 – 45, 47 - 49
VII	Wood & cork and Furniture	Furniture and fixtures-wooden, Wood and wood products
VIII	Paper & Printing and publishing	Paper, paper prods. & newsprint, 46
IX	Petroleum & Chemicals	50 - 61
X	Other manufacturing	62 - 94
XI	Construction	-
XII	Electricity & Water supply	96, 97
XIII	Hotels and rest. & Transp. and comm.	98 – 103, 105, 107
XIV	Wholesale & Retail trade	104, 106
XV	Financial services & Real estate	108,109, 112-115
XVI	Education & Health	110, 111
XVII	Other services	-
XVIII	Public administration	-

Table 12. Structural Decomposition of Forestry Related Sectors using Input-Output Tables, India

Reference Year	ΔM	1st Polar Decomposition			2nd Polar Decomposition			Simple Average of Decomposition		
		Δmq*L1*Y1	mq0* ΔL *Y1	mq0*L0* Δy	Δmq*L0*Y0	mq1* ΔL *Y0	mq1*L1* Δy	½ [Δmq L1 y1 + Δ mq L0 y0]	½ [mq 0 ΔL y1 + mq 1 ΔL yo]	½ [mq 0 L0 Δ y + mq 1 L1 Δy]
1994-1999	3926677	-102190	-96696	4125563	-99332	-65928	4091937	-100761	-81312	4108750
1999-2004	2810488	-2057203	937024	3930667	-1322024	-158945	4291457	-1689614	389040	4111062
2004-2008	14155192	3689747	-96859	10562304	1439086	-78782	12794888	2564416	-87821	11678596
1994-2008	20892357	-2022853	1837858	21077352	-305270	-183433	21381059	-1164062	827213	21229206

Chapter 16
Improving Sustainability of the Environment in a Changing Climate:
Can REDD+ Rise to the Challenge?

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ABSTRACT

The mechanism of Reducing Emissions from Deforestation and Degradation plus conservation, sustainable forest management and enhancement of carbon stocks is emerging as one of the current efforts and actions being developed by the international climate change community to mitigate climate change. This chapter highlights the potentials as well as the challenges of this mechanism to reduce forest loss and improve the health and sustainability of the environment. Main potentials include its resolve to make trees worth more standing than cut, the transfer of funds to support conservation efforts and a focus on delivering social benefits. The main challenges include the less attention on unclear tenure and benefit-sharing framework; weak institutions and the complex historical, political and structural interests which have allowed powerful groups to expropriate the forest resources and trade-offs that may arise during implementation. It then outlines four broad areas where researchers can make contributions in national and local level policy-making and interventions related to REDD+.

INTRODUCTION AND BACKGROUND

There is now widespread recognition that the earth is warming at an unprecedented rate, primarily due to human activities and changes in landuse patterns (Stern, 2007; World Bank, 2009). Scientists have shown that, the health of the environment and general sustainability of planet earth remains very threatened (Rockstrom et al, 2009; Lenton, 2013). Human actions are said to be rapidly approaching global thresholds of the series of nine planetary boundaries that define a safe operating space for humanity (Rockstrom et al, 2009). The assertion that the climate is changing is now almost unequivocal. Floods, high temperatures, ice melting, wars, spread of strange diseases, droughts,

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cyclones, famine, biodiversity loss, economic losses, environmental refugees are few of the well documented consequences of catastrophic climate change (IPCC, 2007). This has spurred international actions and responses to improve the health and sustainability of the environment usually through two means: adaptation strategies to reduce the impacts of climate change and mitigation efforts to reduce greenhouse gas emissions.

One of the current efforts and actions being discussed by the international climate community to mitigate climate change is through the mechanism of reducing emissions from deforestation and degradation plus conservation, sustainable forest management and enhancement of carbon stocks (REDD+). REDD+ was borne out of the recognition that deforestation and degradation contribute about 10-20% of global CO2 emissions (IPCC, 2007; Santilli et al., 2005; Busch and Seymour, 2014), which brings to light the important contribution that the forestry sector can make towards climate change mitigation. As carbon forms a large component of greenhouse gas emissions (GHGs), REDD+ aims to create economic values for carbon stored in trees and provide financial incentives/compensation for countries to reduce emissions from deforestation and degradation and to support conservation and other efforts that improve the health and sustainability of the environment. Individuals, communities, organisations and countries that take practical steps to halt, slow and reduce the rate of deforestation are thus expected to be rewarded through REDD+. For many, REDD+ has exciting potentials and remains an effective and cost-efficient option for mitigating climate change (Angelsen, 2008; Angelsen, Brockhaus, Sunderlin, & Verchot, 2012; Stern, 2007) but like any other public policy, it also has a number of challenges standing in its way to achieve its mission (Angelsen et al., 2012; Arhin, 2014; Hansen, Lund, & Treue, 2009; Parrotta, Wildburger, & Mansourian, 2012). Whether REDD+ will succeed or not therefore remains a question that continuously engage the attention of policy-makers, researchers, businesses and civil society organisations (Visseren-Hamakers, Gupta, Herold, Peña-Claros, & Vijge, 2012) .

The aim of this chapter is to contribute to the debate on REDD+ by sketching out some of its potentials related to slowing the rate of deforestation and improving sustainability of the environment, bringing to the fore a number of challenges that REDD+ faces and highlighting few areas where researchers can make contributions in national and local level efforts. The paper is structured as follows. First, it provides the context and background through which REDD+ became an important policy strategy in climate change discourse before moving on to discuss the potentials of REDD+ to contribute to climate change mitigation. This is followed by a critical look at some of the challenges that could undermine the potentials of REDD+ to improve sustainability of the environment. The next section outlines some broad areas that researchers can focus to make contribution towards REDD+ policies and interventions at national policy formulation and local projects implementation levels. The last section ties the study together through a conclusion.

CLIMATE CHANGE, FORESTS AND REDD+

Climate change is now regarded as the most significant long term development risk of the 21st century (World Bank, 2009). Available scientific evidence has shown that over the last century, as a result of human activities, the global temperatures have risen by close to 0.7°C; sea levels are gradually rising almost at three millimetres a year and consequently contributing to the warming of the Earth (IPCC, 2007). These climatic changes are largely caused by an excess of heat-trapping gases, first and foremost carbon dioxide, methane and nitrous oxides which result from sources such as the burning of fossil fuels, waste dumps and also from agriculture. As the carbon emissions continue to rise, there is a great possibility of significant negative impacts on ecosystems, water resources, food production and food security as well as human health (Eliasch, 2008; IPCC, 2007; Stern, 2007). Scientists predict that millions of people, especially poor people stand the high chance of being exposed to an increased incidence of droughts, famine and floods, unreliable rainfall patterns, hurricanes, rising sea levels, widespread of diseases such as malaria, food and freshwater shortages and the loss of their livelihoods (IPCC, 2007; Smit et al., 2001; Solomon, Qin, & Manning, 2007). In view of their strong reliance on climate-vulnerable sectors such as agriculture, low income countries are particularly highly vulnerable to these effects of climate change (IPCC, 2007; Nelson et al., 2009; Stocker et al., 2013). With the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) as the basis for a global response to the climate change challenge in 1992, this body has spearheaded several agreements including its flagship Kyoto Protocol. These agreements and conventions, though their effectiveness remains contentious, are aimed to meet its core objective to stabilise greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system.

Forests are important part of the problem as well as the solution towards climate change mitigation. Globally, forests are estimated to cover 30% of the Earth's land surface or about ≈4 billion hectares (ha) of land (FAO, 2005). The FAO (2005) estimates that, close to 3.5 billion m3 of wood of 434 billion m3 of growing stock were removed from the forests in 2005 alone. Deforestation and forest degradation remains the second leading cause of global warming, accounting for approximately one-fifth of global greenhouse gas emissions (IPCC, 2007; Santilli et al., 2005; Stocker et al., 2013; van der Werf et al., 2009). As forests are sinks, the destruction of forests emit carbon dioxide into the atmosphere which contribute to climate change. Some studies have reported a net loss of 8.3 million hectares per year between 1990 and 2000 and about 6.2 million hectares per year between 2000 and 2010 (FAO, 2010). This makes the loss, depletion and degradation of forests a cardinal issue for climate change mitigation. In countries, such as Indonesia, Brazil and Congo, forest loss are by far the main source of national greenhouse gas emissions. Deforestation and forest degradation have therefore become a very important issue in climate change discourse over the past few years (FAO, 2010; Millennium Ecosystem Assessment, 2005). In addition to the large contribution that deforestation and forest degradation make to global emissions, tackling both has been identified as one of the most cost-effective ways to lower emissions.

Forests also play an essential role in regulating climate change at various geographical scales as they sequester and absorb vast amounts of carbon—and thereby mitigating against climate change. They further provide essential ecosystem services beyond carbon storage and emissions offsetting including health (through disease regulation), livelihoods (providing income, jobs and employment), water (rainfall generation, watershed protection and water flow regulation). At the local level, they also provide an important role of preventing degradation and surface run-off by functioning to protect soil and soil nutrients (Millennium Ecosystem Assessment, 2005; Parrotta et al., 2012). There has therefore been increasing calls to include approaches of reducing emissions from deforestation and forest loss in post-Kyoto climate change agreements. This is seen as an essential strategy for mitigating climate change and also to improve the health and sustainability of the environment. It is in this context that the mechanism for Reducing Emissions from Deforestation and Degradation plus conservation, sustainable management of forests and carbon enhancement (herein referred as REDD+) has been borne.

BRIEF BACKGROUND OF REDD+ AND COUNTRY LEVEL EFFORTS

REDD+ emerged as a significant part of the solution to the climate change crisis in 2005, although it has a longer history. It has been hailed as a fresh approach; a creative and effective way of managing forests and the hope to save the lungs of the earth (Angelsen et al., 2012). It is emerging as an evolving global policy mechanism to halt greenhouse gas emissions related to land-use in developing countries. The Coalition for Rainforest Nations, led by Papua New Guinea and Costa Rica, formally put the issue on the climate change negotiating agenda with the suggestion that countries showing a real reduction in emissions from historical baselines could receive monetary compensation. This was during the 11th Conference of the Parties (COP 11) of the UNFCCC in Montreal, Canada in 2005; but it was during the COP 13 in Bali, 2007 that it officially became part of the international climate agenda when parties to the UNFCCC committed to address climate change through the Bali Action Plan and the Bali Road Map. In 2009 at the 15th session of the conference of the parties to the UNFCCC in Copenhagen made attempts at clarifying the scope, financing impetus and other technical requirements of the mechanism. The scope of the mechanism was finally defined during the COP 16 in Cancun, Mexico (Angelsen & McNeil, 2012; Pistorius, 2012). REDD+ is understood within the UNFCCC as policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation; and the role of conservation, sustainable management of forest and enhancement of forest carbon stocks in developing countries' (Bali Action Plan, para 1 (b) (iii)). These activities are often expected to be country-driven, promote co-benefits and biodiversity, actions that are consistent with conservation of natural forests, involvement of indigenous peoples and local communities as well as transparent forest governance (UNFCCC, 2011). In view of its focus context-specific diversity of approaches, REDD+ is also understood as an umbrella term for local, national and global actions that reduce emissions from deforestation and forest degradation, conserve, enhance forest carbon stocks and sustainably manage forest in developing countries (Angelsen, 2009).

Although negotiations on the mechanism at the level of COP have been evolving since about 2007, it was during COP 19 in Warsaw in 2013 that significant breakthrough was made on six main decisions involving the coordination of: financial arrangements, transparency and safeguards, national forest monitoring systems, verification at the international level, institutional arrangements, and drivers of deforestation (Sills et al, 2014; Arhin, 2014; UNFCCC, 2014; Stolle and Alisjahbana 2013). The decisions at Warsaw—known as the Warsaw REDD+ Framework—almost brought to an end all the technical and carbon-related discussions and requirements for participation in REDD+. Current negotiations are focused on the Non-carbon benefits of REDD+. REDD+ is very much expected to become an important part of a new climate deal likely to be reached during COP 21 in Paris in 2015. Other issues that still remains outstanding include what the specific financial mechanisms for REDD+ are, whether market-based REDD+ is to be allowed, and whether REDD+ credits can be used by developed countries to meet their post-2020 commitments. These are expected to be discussed and negotiated during COP 21 in 2015 where a new climate is expected to be reached—of which REDD+ remains a significant part.

When REDD+ emerged, its original idea was simple: to create incentives for developing countries to conserve and keep their forests standing, as deforestation remains an important cause of carbon emissions. REDD+ was anticipated to generate billions of financial resources to pay for the opportunity costs of forest conservation. Inherent in the idea of REDD+ was to create a performance-based, conditional system that would reward stakeholders and other identifiable actors who avoid deforestation and degradation of forests. In order to assess progress at which the rate of deforestation is being achieved, remote sensing technology was expected to be applied toward verifying avoided deforestation in relation to a pre-established reference level. REDD+ primarily sought to spur innovations that would overcome decades of failure and disappointments in attempts to reduce deforestation in tropical countries. The UNFCCC decisions on REDD+ requires countries participating in REDD+ to among other things develop (a) a national strategy or action plan; (b) a national forest reference emission level and/or forest reference level (c) a robust and transparent national forest monitoring system for the monitoring and reporting of the activities and (d) a system for providing information on how safeguards are being addressed and respected throughout the implementation of the activities, while respecting sovereignty. During the COP 16 in Cancun, Mexico, a three-phased non-sequential approach was recommended and adopted for REDD+ (paragraph 73, Decision 1 CP.16), namely readiness and strategy development (Phase 1), early implementation (Phase 2), and performance-based actions (Phase 3). The phase one focuses on readiness actions such as planning, establishment of forest reference levels or reference emission levels, MRV and benefit-sharing frameworks, and safeguard information systems. In phase 2, countries are also expected to continue with their readiness towards a focus on demonstrations and pilots, capacity-building initiatives and development of institutional, regulatory and policy frameworks. The phase 3 is where full-fledged REDD+ implementation with an expectant results-based rewards are expected. While negotiations were ongoing over the years, about 400 demonstration projects, schemes and interventions labelled as REDD+ readiness began across over 70 countries with the aim of testing the idea and developing technical and institutional capacity in developing countries (Gallemore & Munroe, 2013; Minang et al, 2014). Amongst the most important international initiatives supporting national REDD+ readiness are the UN-REDD Programme launched in 2008 and the Forest Carbon Partnership Facility (FCPF) Readiness fund launched in December 2007. Of course, there are several other bilateral agreements on REDD+ projects ongoing such as the $1 billion Indonesia-Norway agreement on REDD+. The UN-REDD Programme is a partnership between the United Nations Food and Agriculture Organization (FAO), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP) to build capacity of national governments to prepare, build institutions and systems that will effectively contribute to reduction of deforestation and degradation. To date, the UN-REDD has supported over 50 partner countries across the world (UN-REDD, 2014). These include Argentina, Bangladesh, Plurinational State of Bolivia, Cambodia, Colombia, Côte d'Ivoire, Democratic Republic of the Congo (DRC), Ecuador, Indonesia, Mongolia, Nigeria, Panama, Papua New Guinea, Paraguay, the Philippines, the Congo, Solomon Islands, Sri Lanka, the United Republic of Tanzania, Viet Nam and Zambia. Other partner countries are: Benin, Bhutan, Cameroon, Central African Republic (the), Chad, Chile, Costa Rica, Dominican Republic, Equatorial Guinea, Ethiopia, Fiji, Gabon, Ghana, Guatemala, Guinea Bissau, Guyana, Honduras, Kenya, Lao Peoples' Democratic Republic (the), Liberia, Madagascar, Malawi, Malaysia, Mexico, Morocco, Myanmar, Nepal, Pakistan, Peru, South Sudan, Sudan (the), Suriname, Togo, Tunisia, Uganda, Vanuatu and Zimbabwe. It is worthy to note here that some countries (e.g. Vietnam, the Democratic Republic of Congo (DRC), Indonesia, and Tanzania) receive both UN-REDD and FCPF funding.

The FCPF is similarly a global partnership of developed and developing countries which has the World Bank as trustee and main delivery. As of February 2015, there were forty-seven developing countries (18 in Africa, 18 in Latin America, and 11 in the Asia-Pacific region) engaged in the FCPF Readiness (Forest Carbon Partnership Facility, 2015). Other notable funding mechanisms supporting readiness activities include the FCPF Carbon Fund, the Forest Investment Program (FIP), the Amazon Fund, the Congo Basin Forest Fund (CBFF) and the BioCarbon Fund Initiative for Sustainable Forest Landscapes (ISFL). A number of studies have reported on country-level progress in REDD+ Readiness including India (Aggarwal, Das, & Paul, 2009), Kenya (Bernard et al, 2014), Cameroon (Dkamela, 2011) and Tanzania (Burgess et al., 2010; Kweka, Quail & Campese, 2014). Other countries where progress has been published through the academic outlets include Cambodia (Bradley, 2011), Nepal (Ojha et al, 2014; Acharya et al, 2009), Vietnam, (Do & Catacutan, 2014; Ba, 2014), Peru (Robiglio et al, 2014; Menton, Gonzales and Kowler, 2014) and Indonesia (van Noordwijk, 2013). Many of the country level REDD+ readiness actions have so far focused largely on phase 1 and phase 2 of the expected three-phase approach with a focus on planning and coordination activities; development of policies, laws, and institutions; development of monitoring, reporting, and verification systems; assessment of financing and investment requirements; benefit sharing arrangements and frameworks; and demonstrations and pilots (Minang et al, 2014).

One of the strongest motivations behind REDD+ is to incentivise a departure from historic trends of increased deforestation rates and greenhouse gases emissions. It aims to achieve this by creating a financial value for the carbon stored in forests which consequently offers incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. It was thus conceived, originally, as a market-based carbon-offsetting scheme, where different actors in developed countries (e.g., individuals with ethical or voluntary motivations and firms assigned with emissions caps) would have the opportunity to pay agencies and actors in developing countries to reduce deforestation below a projected counterfactual scenario (Angelsen & McNeil, 2012; Pistorius, 2012). Technically, REDD+ interventions should do no harm to communities living around forests, avoid leakage and permanence and deliver emission reduction and development benefits (Angelsen, 2008; Brown, Seymour, & Peskett, 2008). The emissions reduced should be measured, reported and verified before any rewards can be paid. Invariably, REDD+ is primarily an incentive-based and results-driven environmental policy with much potential to improve the health and sustainability of the environment. Judging by the sheer number of projects and interventions ongoing in a relative short time through which REDD+ emerged (i.e. 2005), one may wonder what is it about it that makes it appealing among policy-makers in these countries? In the section that follows, some of the basis, arguments and narratives behind the enthusiasm about the potentials of REDD+ have been outlined.

WHAT DOES REDD+ BRING TO THE TABLE TO IMPROVE THE HEALTH OF THE ENVIRONMENT?

A number of arguments, narratives and explanations are behind the roles, potentials and enthusiasm of REDD+ as a mitigation strategy to reduce forest loss. First, REDD+ is touted to hold massive carbon sequestration potentials as it can reduce emissions in a cheap and less costly manner. Deforestation is regarded to be the most single largest source of about 20% of greenhouse gas emissions (IPCC, 2007; Santilli et al., 2005). Some scientists and practitioners have pointed out that, the world's tropical forests store close to 471 billion tons of carbon—more than all the carbon dioxide ever emitted from burning fossil fuels across the world (Pan et al, 2011; van der Werf et al., 2009). However, 5 to 11 billion of these tons are released annually to the atmosphere from deforestation (Busch and Seymour, 2014). Halting deforestation through REDD+ interventions is seen as an important contribution towards climate change mitigation. The IPCC (2007) estimates that net emissions from forest loss could contribute to about 11 percent of global emissions. Other works by researchers from the Centre for Global Development has also made a compelling case that tropical forests could offset up to 38 percent of total annual greenhouse gas emissions, or up to 48 percent of all greenhouse gas emissions from non-forest sectors (Busch and Seymour, 2014). Some scientists have also estimated that a 50% reduction in the rate of deforestation by 2050 and then maintaining them at this level until 2100 would avoid the direct release of up to 50 GtC this century (Gullison et al., 2007). These studies bring to the fore the massive potentials offer by REDD+ interventions to contribute to climate change mitigation. Further works by economists and other researchers have also given an insights that actions to slow, halt and reverse deforestation under the banner of REDD+ could be cheap and fast—compared to other technical mitigation options such as carbon storage and capture or geo-engineering (Gullison et al., 2007; Stern, 2007). Some studies reveal that forestry mitigation options have the economic potential at costs up to 100 US$/tCO2-eq to contribute 1.3-4.2 GtCO2-eq/yr (average 2.7 GtCO2-eq/yr) in 2030. Under this scenario, about 50% can be achieved at a cost under 20 US$/tCO2 (IPCC, 2007). Further studies and reviews (e.g. Stern, 2007) also estimated that just around US$5 billion in revenues would be foregone as a consequence of protecting forests. Invariably, REDD+ promises to be a very cheap and cost-efficient approach of reducing greenhouse gas emissions, although it has equally proven to be more expensive in the short term due to reforms and other institutional cost of which these estimates ignored. Controlling deforestation and degradation is seen as a major win in the battle against climate change and the general improvement of the health of the environment. The recent experience of Brazil has been exemplary and has served to show the high potential of REDD+ actions for massive reduction of carbon emissions in the forest sector. Focusing on measures such as increased law enforcement efforts, withholding of credit from high-deforestation municipalities and establishment of protected areas, Brazil experienced a 79% reduction in its rate of deforestation between 2004 and 2013 (Springer and Wolosin,2014; Busch and Seymour, 2014). This has won it an international recognition as a country that has to date made the largest contribution to reduced GHG emissions (Springer and Wolosin 2014; Boucher, Roquemore & Fitzhugh, 2013). Quite remarkably, the reduction in rate of deforestation in Brazil was accompanied by increases in production of soy and cattle, which are the two main drivers of forest loss in the Amazon region. While much of the policy actions pre-date the REDD+ era, it nevertheless show how REDD+ can be a catalyst for reducing deforestation and carbon emissions. This reflects one of the reasons why there is so much confidence and investments into about 400 REDD+ projects across more than fifty countries by donors such as the World Bank, the Norwegian government and some UN institutions such as the UNEP, UNDP and the FAO.

Secondly, by its design, REDD+ is supposed to make it more economically attractive to conserve forests than putting it to alternative uses such as forest clearing or to degradation through unsustainable use (Angelsen et al., 2012). One of the defining characteristics of REDD+ as a strategy for improving the health and sustainability of the environment relates to its focus on incentives. Proponents argue that deforestation occurs because in the prevailing economy where environmental costs are externalised, forests are worth more cut than standing. Thus, the chopping down of trees for uses such timber exports, charcoal burning, agricultural production and others--which releases carbon into the atmosphere--results from the lack of incentives or appreciation of the values of standing trees. However, by providing financial incentives, REDD+ hopes to radically reverse this practice so that forests can worth more standing than cut down (Brockhaus & Angelsen, 2012; Di Gregorio, Brockhaus, Cronin, & Muharrom, 2012). The value of such incentives to be provided by REDD+ are expected to worth more than what agents of deforestation might have got from cutting down the trees. Experiences in countries to date suggest that several national governments are revising, reforming and reviewing policies to provide incentives that will make individuals and other economic agents preserve forest resources. For example, there are now over 20 countries including Tanzania, Vietnam, and Cameroon who are reforming land and tree tenure legislative frameworks to provide incentives for forest conservation practices (Larson et al, 2013). In Ghana for instance, there is also now a renewed attempts at reforming the country's statutory natural resources revenue sharing formula which hitherto excludes individuals and landowners who cater for naturally regenerating trees as a way of providing incentives for farmers to keep those trees on their farms (Forest Commission, 2014, personal communication). While the need for institutionalisation of incentives in forest management policies and practices are gaining traction across countries, whether such incentives will be enough to slow, halt and reverse deforestation and degradation rates still remain important policy gaps, which go beyond the scope of this paper.

Related to the above is the availability of finance that is expected to be engineered by REDD+ to support the implementation of forest preservation policies. A number of studies has drawn attention to the fact that finance to implement national forestry policies have remained a challenge in several developing countries over the past decades (Balmford & Whitten, 2003; Laurance, 2007). This financial constraint has thus inhibited the implementation of otherwise beautiful projects, plans and policies that would have preserved forests and improved the health of the environment. REDD+, its strongest proponents argue, also offers an unprecedented source of funds for national governments and other actors who are struggling to generate funds to implement policies that effectively reduce deforestation and promote forest preservation. This envisaged funds are expected to come from market and private sources, multilateral and even bilateral partnerships. Some estimates have put the funds available through REDD+ in the order of around US$2 billion to $30 billion annually (Ebeling & Yasué, 2008; Stern, 2007). Indeed, between 2008 and 2010 there were about $7 billion that were committed to implement diverse REDD+ interventions across different countries (Simula, 2010; Creed and Nakhooda, 2011;). While market sources and funding for REDD+ still remain lower than expected (Sills et al, 2014), country experiences to date has generally demonstrated the potentials of REDD+ to leverage significant funds for forest management policies—at least in some tropical countries. In Ghana for instance, about $104 million (including pledges) has so far been mobilised to implement diverse forest management activities under the banner of REDD+ (Asare et al, 2014). In Congo, $61.5 million has already been committed for REDD+ interventions while the Papua New Guinea has also mobilised $26.4 million for REDD+ activities (Canby et al, 2014) . By making funds to pursue conservation goals readily available, REDD+ is thus expected to go a long way of contribute to improving the health and sustainability of the environment.

Fourth, REDD+ interventions are also expected to target the underlying (i.e. indirect) drivers of deforestation and degradation rather than just the proximate causes (i.e. direct) which have been the dominant policy approach in the past. The causes of deforestation and degradation are diverse. With its mission to significantly reduce forest loss, policies, projects and interventions on REDD+ are encouraged to focus not just on the proximate or direct causes but also on the underlying drivers of deforestation and degradation. Proximate causes refer generally to the human activities or the immediate actions and activities that directly impact on forest cover. These include but not limited to extension of commercial and subsistence agriculture into forests, mining, infrastructure expansion, logging, urban expansion, livestock grazing in forests and wood extraction for purposes such as fuel and charcoal production (Geist & Lambin, 2001, 2002; Hosonuma et al., 2012). Focusing on the underlying causes of deforestation involve a conscious analysis of the complex interactions of the structural social, economic, political, cultural and technological processes that are often distant from their area of impact but greatly influence forest loss (Hosonuma et al., 2012). They are related mostly to international (e.g. markets, commodity prices), national (e.g. population growth, domestic markets, national policies of raising foreign exchange from timber exports, natural resource governance framework) and local circumstances (such as change in household behaviour). The careful focus on both direct and indirect drivers means that REDD+, it is argued, holds much promise in tackling the root causes of forest loss--a step which is essential in improving the health of the environment. The ongoing readiness activities in several countries have already exhibited this potential. To date, all countries participating in REDD+ interventions have been required to focus on the complex political, social, governance, economic and ecological drivers of deforestation and degradation. For instance, in Vietnam, the main proximate causes of deforestation has been identified as 1) land conversion for agriculture,2) land conversion for infrastructure, especially hydropower installations; 3) unsustainable logging (both legal and illegal logging); and 4) forest fires (Government of Vietnam, 2010; Pham et al, 2012). The Government has further identified underlying or indirect drivers as growing demand for forest products and agricultural land driven by population growth and migration, economic growth and increasing demand for wood for the pulp and paper industry, construction and fuel (Sunderlin and Huynh 2005).Similarly, REDD+ has also contributed to a conscious focus on identification of both immediate and underlying drivers of deforestation by the Government of Ghana. This has led to a policy focus on not just immediate drivers-- such as the burgeoning population; high demand for wood and forest products on the international market; heavy dependence on charcoal and wood fuel; limited technology development in farming systems; reliance on cyclical 'slash and burn' methods to maintain soil fertility-- but also the broader set of complex demographic, economic and policy factors that influence these drivers of deforestation (Forestry Commission, 2010).

Fifth, many are of the opinion that REDD+ holds further promise to bring about transformational change and deliver win-win or triple dividends for climate, forests and poverty reduction. Thus, beyond its climate change focus REDD+ offers a number of benefits including poverty reduction and improved rural livelihoods, biodiversity conservation, water regulation and other social benefits, such as jobs, land tenure clarification and enhanced participation of non-state actors in decision-making under stronger governance (Angelsen, 2009; Parrotta et al., 2012) . For example some researchers estimates that as many as 2,472 forest species including amphibians, birds, and mammals would have been in existence REDD+ had been implemented on a large scale during 2005–2010 (Busch, Godoy, Turner, & Harvey, 2011; Strassburg et al., 2010). Additionally, REDD+ is seen as important opportunities to reduce poverty and enhance equity due to its strong possibility of delivering significant financial flows to remote areas, which are among the most depressed and underfunded parts of most developing economies(Brown et al., 2008). Also, with over 1.6 billion people depending on forests at various degrees, improving the health and sustainability of the forests resources through REDD+ is expected to support the livelihoods, assets and capabilities of these individuals, groups and communities. For example, the Green India

Mission launched recently aims to among other things increase forest/tree cover on 5 m ha of forest/non-forest lands and improve quality of forest cover on another 5 m ha (a total of 10 m ha); improve ecosystem services, enhancing annual CO2 sequestration of 50-60 million tonnes by the year 2020 and increase forest-based livelihood income for 3 million forest dependent households (Ravindranath & Murthy, 2010; Sharma & Chaudhry; Sarkar, 2011). The enthusiasm and appealing nature of the potentials of REDD+ have therefore thriven on several of these arguments. But whether REDD+ will rise up to the challenge of improving the sustainability of the environment is still early to be determined. Indeed, there are number of factors that may act as stumbling blocks for REDD+ in realising these potentials. This remains focus of the ensuing section.

POTENTIAL CONSTRAINTS AND CHALLENGES OF REDD+

While on the surface, REDD+ has a number of potentials, it has also been met with scepticism, concerns and even outright rejection by some stakeholders such as indigenous communities at both national and global levels. Invariably, REDD+ is inherently fraught with a multitude of problems and challenges which might affect its application and the potentials it presents in improving the health and sustainability of the environment. Here, three of these challenges and concerns have been outlined.

The first is rooted in the quick and cheap emission reduction strategy narrative. It is a common assumption among advocates that REDD+ will present an easy, less costly and a very quick way of reducing emissions compared with approaches such as carbon capture and storage, fuel switching and other greenhouse gas abatement options (Stern, 2007). However, this assertion is now understood to be based on simplistic assumptions about the prevention of forest loss. Blackman (2010) argues that much of the evidence of the quick and cheap narrative are based on opportunity cost analysis of the leading activities that result in tree cover loss and a broad consideration of transaction costs tacked on. They largely ignore weak regulatory institutions, corruption, conflated property rights, and an abundance of small-scale drivers of tree cover loss (Blackman, 2010; Chomitz, Buys, De Luca, Thomas, & Wertz-Kanounnikoff, 2007). Even more importantly, the quick, cheap and cost-effective narrative of REDD+ also appears to ignore the fact that the causes of deforestation and degradation, to which REDD+ aims to halt, is rooted in complex historical, political and structural interests which allow powerful groups to expropriate the forest resources. There is therefore vested and entrenched economic interest which drive deforestation, of which it will not be less costly to be dispelled by REDD+. As Hansen et al (2008) had shown in the case of Ghana, there is a political economy that gives priority to economic development over forest conservation, while simultaneously allowing the political and administrative elite to financially benefit from resource depletion. Will REDD+ be able to shift attitudes of countries that had traditionally relied on timber production and export to generate foreign exchange for its economic development? Abandoning such practices will not be easy. In brief, forest conservation policies and reforms that are envisaged under REDD+ to improve the health and sustainability of the environment thus underestimate the challenges ahead in many countries; and will not come fast, easy, quick and cheap.

Secondly, proponents have advanced the 'big economic compensation' narrative as one of the defining characteristics which will propel of REDD+ to rise to the occasion of improving the health and sustainability of the environment through reduction in forest loss. But some critical questions still remain. For instance, who will receive this monetary compensation? Is it national government? Is it communities that live in and around the forests? Is it Non-governmental organisations who will carry out conservation efforts? Herein lies another challenge that will stand in the way of REDD+ to effectively contribute to the health and sustainability of the environment. Benefit Sharing framework remains an important design feature of REDD+. This is expected to create positive incentives; generate the support of actors who might otherwise be involved in forest destruction activities and also avoid leakage and ensure permanence (Angelsen et al., 2012; Balderas Torres & Skutsch, 2012; Peskett, 2010). Yet, many countries do not have a fair benefit sharing frameworks (Costenbader, 2009; Pham et al., 2013). In several of the tropical countries that are engaged in REDD+, it is unclear who the legitimate beneficiaries of the REDD+ monetary compensations are; it is unclear what an efficient distribution of costs will be; it is unclear what structures will be in place for financial transfers and even the processes for decision making, implementation and distribution of REDD+ benefits? Coupled with this relates to the land tenure puzzle that has not been solved in several tropical countries (Cotula & Mayers, 2009; Karsenty, Vogel, & Castell; USAID, 2011). The importance for recognising and clarifying land rights is largely recognised and at times presented as even a condition for the implementation of REDD+. The Stern Review for instance reiterated that "at a national level, defining property rights to forestland … and determining the rights and responsibilities of landowners, communities and loggers, is key to effective forest management" (Stern, 2007: 603). Whilst land and forest tenure issues are important to REDD+ success in general, they are even more important in enhancing equitable and just benefit to both men and women in local settings. In many countries, local communities have no secure access to land. The absence of secured land rights especially to women mean that there will be no guarantees for the receipt of reward for their extensive forest conservation efforts. For a sector, where rent seeking and entrenched financial gains have contributed to unsustainable exploitation of resources (Larson & Ribot, 2007; Ribot & Larson, 2012; Sikor et al., 2010), failure of REDD+ to adequately establish a secured tenure regime and clear, fair and equitable benefit sharing framework will cast a slur in its potential to improve the health and sustainability of the environment.

Third, the win-win climatic and socio-economic development benefits that have ignited enthusiasm in the potentials of REDD+ also has several limitations. Indeed, many have drawn attention to the fact that win-win outcomes are not always possible--and really hard to come by (Gupta, 2012; Visseren-Hamakers, McDermott, Vijge, & Cashore, 2012). A number of studies have thus drawn attention to the fact that implementation of REDD+ will involve serious trade-offs--and not necessarily win-win outcomes. This is because in order for REDD+ to be effective in protecting the environment, strategies such as evictions, resettlements, forceful relocation, limiting access to forest resources might all have to be employed. But the application of these strategies will largely have negative, not positive, consequences for the people and communities that live in around the forests. It is for these and many more reasons that the UNFCCC has advocated for safeguards to manage these risks (Arhin, 2014). Thus, while the potential for REDD+ to improve livelihoods may provide incentives for forest preservation, concerns about respect for local land rights and livelihoods and even the lack of benefits not getting to local communities might act as stumbling blocks towards in reducing forest loss in several countries.

ROUTING REDD+ THROUGH SUSTAINABILITY: AN AGENDA FOR RESEARCHERS?

The foregoing discussion has drawn attention to both the potentials and some challenges of REDD+. As discussion of the mechanism is still ongoing at both global and national levels, researchers and scientists will have important roles to play in highlighting lessons, new evidence and information that will be useful for policy-making. Four areas are particularly important in this context. First, researchers have important roles to play in tracking narratives and discourses behind REDD+ interventions in different countries and also in specific local contexts. Discourses and narratives are representations of reality. They represent the dominant understandings, perspectives, knowledge and expectations of a policy idea such as REDD+. They are stories with beginning, middle and end (Roe, 1991, 1994) and often set the boundaries upon which actions and resources needed to achieve a particular policy goal are generated. As an idea whose specific mission is to reduce emissions and improve the sustainability of the environment, we must constantly ask to what extent are the REDD+ interventions in the over 70 countries (Gallemore & Munroe, 2013) delivering on this mission? This is a task that falls in the domain of researchers and scientists. Tracking discourses and narratives about REDD+ in specific countries primarily involves finding answers to questions as: How has the problem that REDD+ intends to solve in particular contexts been defined? What actions and strategies have been identified by REDD+ interventions to solve the problem of deforestation and degradation? Do the actions or solutions match the identified problems? What has been missed in the analysis of problems and solutions in the REDD+ policy arena? How contestation between alternative pathways and goals is playing out, particularly between proponents of REDD+ and critics? What roles have been attributed to by different actors in solving the deforestation and degradation in specific contexts? By constantly asking these questions, researchers will be in a better position to contribute to understanding of different pathways of REDD+: whether they are truly on the 'right' course to improve the health and sustainability of the environment or otherwise.

Secondly, an important role and contribution that researchers can make in the context of REDD+ lie with a focus on contributing to nuanced understandings of the various drivers of deforestation and degradation. Effective identification of both proximate and underlying causes of forest loss is inherently critical for REDD+ if it is to rise to the challenge of improving the health and sustainability of the environment. Yet, it remains the most understudied theme in the REDD+ debate (Kissinger & Herold, 2012; Visseren-Hamakers, Gupta, et al., 2012). Scientists and researchers interested in the potentials of REDD+ to address climate change need to focus on diverse drivers of land-use changes, the linkages between such land-use change processes, the different actors, interests and dynamics contributing to forest loss and impact and effectiveness of existing policy measures to address these drivers.

Researchers can also make important contributions about the potentials of REDD+ with much focus on the science and economics of the mechanism. By economic analysis, researchers can provide informed analysis to policy-makers in relation to whether the benefits of implementing REDD+ outweigh the costs, what and which least-cost opportunities, or options are available to achieve the goals of REDD+ and the impact of REDD+ policy interventions on different sectors of the economy. Such analysis is important for planning and decision-making about REDD+ policies, programs and projects. Even more importantly, it is also important for researchers to focus on the science of REDD+ including the carbon sequestration potentials of different types of species of trees, actual emissions that will be reduced, temperature and weather conditions that will be ideal for trees to grow and how to deal with invasive species that might counter conservation efforts.

Last but not the least, one other where researchers can make a contribution to advance understanding about the potentials of REDD+ is in the area of the governance of the mechanism. Governance, in the context of natural resource management, usually relates to who makes decisions and how decisions are made, at what different scales from global through to national to local, the formal and informal institutions and rules, power relations and practices of decision making (Larson & Petkova, 2011; Sandbrook, Nelson, Adams, & Agrawal, 2010). As many scholars have already pointed out the prevalence of deforestation and degradation in several countries is largely as a result of the governance framework of natural resources. For example, continuous exclusion of timber revenues and destructions caused by timber concessionaires have resulted in some local farmers in Ghana having to kill forest trees before they mature (Kotey et al., 1998). Exclusions, lack of participation of some important actors, unfair benefit-sharing arrangements among others have all played diverse roles to promote deforestation and degradation. For REDD+ to be effective in promoting the sustainability of the environment, questions such as who benefits from forest conservation efforts, who participates in the REDD+ decision-making process, in what spaces and capacity do they participate, how they participate, the mix of state and non-state actors, the power relations between different groups engaged in the REDD+ processes all have important implications and should remain the focus of researchers and scientists. It is a common knowledge that forest policies and programs seldom reflect interest and aspirations of local forest users'. This apparent disconnection occurs partly due to the fact that there is often very limited opportunities for dialogue between state actors who manage resources and communities that live around the forest areas. Interestingly, there has been relatively few field-based examination of local perspectives and participation in REDD+ although many of the ongoing initiatives focus on areas managed by local communities or smallholders (Cromberg, Duchelle, & Rocha, 2014). By focusing on the governance side of REDD+, researchers can contribute to fair, transparent, just and equitable REDD+.

CONCLUSION

The reality of climate change across the world has firmly been established in literature. It is in the context of the need to mitigate climate change and to improve the health and sustainability of the environment, that the international climate change community is making negotiations on REDD+ as part of the UNFCCC's post-Kyoto agreements. Sustainability now firmly remains an important component of the post-2015 development framework currently being developed by the international community (Kumi et al, 2014; Griggs et al, 2013). Proponents of REDD+ see it as a game changer with massive carbon sequestrating potentials. Its potential lies with the fact that it is expected to reduce emissions in a cheap and less costly manner; to make it more economically attractive to conserve forests than putting it to alternative uses; to transfer large funds to support the implementation of forest preservation policies in tropical countries and to deliver win-win or triple dividends for climate, forests and poverty reduction. These potentials have triggered much interests, enthusiasm and investment in several countries. But the question that naturally arises is: can REDD+ rise to the challenge of reducing emissions from the forestry sector and thereby improve the health of the environment? It is too early to have a conclusive or definitive answer to this question. Yet, as this chapter has shown a number of challenges stand in the way of REDD+ to deliver its mission. First, it will neither be fast nor easy to reduce forest loss as it is often assumed by REDD+ proponents. This because this assertion ignores factors such as weak institutions, corruption and the complex historical, political and structural interests which have allowed powerful groups to expropriate the forest resources. Second, unclear tenure and benefit-sharing framework could act against the many potentials inherent in REDD+. Third, win-win outcomes are not always possible. REDD+ will involve trade-offs which may act as counter-productive if not managed well. Amidst these challenges, researchers and scientists have important roles to play to contribute to policy-making and move REDD+ in a desirable direction of improving health and sustainability of the environment. Key themes for future research involve tracking narratives and discourses employed in specific national and local contexts, identifying drivers of deforestation and degradation, critically examining the science, economics and the governance aspects of REDD+ interventions. In effect, scientists and researchers have an important role to play in advancing knowledge, by examining critically existing body of knowledge and by building capacity of the wide array of actors involved in REDD+ policy development in different contexts. This can be achieved through multi-disciplinary approach.

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Section 7

Land and Adaptation

Chapter 17
Lack of Land Tenure Security as Challenges to Sustainable Development:
An Assessment in the Context of Bihar, India

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ABSTRACT

Tenural security towards land has far-reaching and long lasting socio-economic implications. Secured tenural right over land found as influencing factor in utilising the land in more efficient way, do investment as well as precondition for environmentally sustainable natural resource use. Though there are numerous laws have been initiated in Bihar to ensure land right and equity in distribution, but their implementation to ensure land tenure security is a far cry. The lack of tenural right, theoretically, paves way for two problems towards sustainable development; in one hand it restrict the sharecropper to undertake a long term investment in the land to increase productivity, on the other hand this might have created the problem termed as 'tragedy of commons'. The study made an assessment of the legal framework and argues for proper legal initiative and effective implementation to protect land tenure security for sustainable development.

1. INTRODUCTION

In rural as well as urban area land is the key source of income and livelihood. It, as argued, provides foundation for economic activities and functioning of market and non-market institutions (Deininger K., 2003). Land has become a significant resource in the context of economic development, rapid urbanization and industrialization, increase in food demand, climate change and sustainable development. The importance of land in the 21st century is lies in the context of sustainable, sensitive and inclusive development. In this context, tenure security of land is critical for sustainable development of agriculture and livelihood. Land Tenure system is the relationship, whether legally

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or customarily, among people, as individuals or groups, with respect to land. The land tenure system, is also viewed as an institution i.e., rules invented by societies to regulate behaviour. These rules of tenure define how property rights to land are to be allocated within societies as well as define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. The land tenure systems determine who can use what resources for how long, and under what conditions (Food And Agriculture Organisation, 2002). For people, especially rural people land holding constructs its social identity. Secured access to land not only reduces uncertainty and vulnerability towards livelihood options it also ensure sustainable development. It is argued that tenural insecurity may arise if the property right are not recognised; this also paves way for disputes, conflicts. Ambiguous rights or ambiguity regarding who holds the rights can reduce transactions, blocking the transfer of land to more efficient uses (World Bank, 2012). When resource tenure and property rights are insecure, the potential for sustainable resource management is undermined.

Bihar is one of the poorest states in India. Located in the most densely populated part of India, Bihar is India's third most populated state. Bihar has a total population of 103.811 million people of whom 89% live in rural areas with agriculture being a key economic activity. The state accounts for 2.88 per cent of India's land mass but supports 8.58 per cent of the country's population (Census India, 2011). The state is characterised with low per capita income, low level of education, high fertility rate, high population density and dependency upon agricultural sector. The situation of women in Bihar is a matter of concern. The Census India (2011) recorded Bihar as the state with lowest female literacy rate. Women in Bihar also found resource less and voiceless. As it is argued that, norms and culture of the society in general, as well individual knowledge and ability, give negotiation power and voice (Agarwal, 1997), the tenural right and security argued to empower women with more sustainable livelihood options.

Given this background the present paper attempts to assess the challenges of lack of tenure security in the context of Bihar and how it influence sustainable development. The assessment is done based on existing acts, laws to assess the legal framework and secondary data collected from concerned government offices to assess enforcement of tenure security. Accordingly, the paper has been divided into following sections. Section II develops a conceptual framework of land tenure system and discusses the historical background of land tenure system in Bihar. Section III discuss the theoretical framework of land tenure security and assess recognition of land tenure security in Bihar. Section IV discuss about the concept of Sustainable Development and establish the linkages between sustainable development and Tenure Security in the context of Bihar. Section V draws implication and concludes the study.

2. LAND TENURE SYSTEM: CONCEPT AND HISTORY

2.1. Land Tenure System: A Conceptual Framework

Land Tenure system is the relationship, whether legally or customarily, among people, as individuals or groups, with respect to land. The land tenure system, is viewed as an institution i.e., rules invented by societies to regulate behaviour. These rules of tenure define how property rights to land are to be allocated within societies as well as define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. The concept of 'tenure' is a social construct that also defines the relationships between individuals and groups of individuals by which rights and obligations are defined with respect to control and use of land (Economic Commission for Africa, 2004). For people, especially rural people, land is not only source of shelter, income and livelihood; it also constructs the social identity. Secured access to land not only reduces uncertainty and vulnerability towards livelihood options it also ensure sustainable development. This issue, as argued, that as natural resource base upon which the continent largely depends for its socio-economic development; it has been greatly influenced by tenure type. The continuing degradation of these resources over the years is considered a major setback to the attainment of sustainable development (Economic Commission for Africa, 2004).

It is argued that tenural insecurity may arise if the property right are not recognised; this also paves way for disputes, conflicts. Ambiguous rights or ambiguity regarding who holds the rights can reduce transactions, blocking the transfer of land to more efficient uses (World Bank, 2012). In one hand, where the tenure security on land considered to be the very basis of economic, political and social power and status (Rukuni, 2000) it is also considered an important precondition for increasing land-based economic development and environmentally sustainable natural resource use (Bruce & Migot-Adholla, 1994). However, both statutory and customary tenure systems are under stress in the face of global demographic growth, growing food scarcity, and environmental degradation of land, fisheries, and forest resources—compounded by the forces of global climate change (United State Agency for International Development, 2013). The Land tenure system have been categorised in the following four categories by Tenaw, Zahidul Islam, & Parviainen (2009)

1. **Private:** The assignment of rights to a private party who may be an individual, a married couple, a group of people, or a corporate body such as a commercial entity or non-profit organization.
2. **Communal:** A right of commons may exist within a community where each member has a right to use independently the holdings of the community. For example, members of a community may have the right to graze cattle on a common pasture.
3. **Open Access:** Specific rights are not assigned to anyone and no-one can be excluded. This typically includes marine tenure where access to the high seas is generally open to anyone. An important difference between open access and communal systems is that under communal system non-members of the community are excluded from using the common areas.
4. **State:** Property rights are assigned to some authority in the public sector. For example, in some countries, forestlands may fall under the mandate of the state, whether at a central or decentralized level of government.

However, access to secure land and shelter, widely accepted, as a precondition for access to other services and livelihood opportunities (Rakodi & Lloyd-Jones, 2002). With this importance of secured land tenure, there is historical background related to ensure tenure security initiative in Bihar. The following section shall discuss about the historical process of ensuring tenural right in the context of Bihar.

2.2. Land Tenure System in Bihar: A Historical Background

The historical background of land tenure system in Bihar can be traced back in the year of 1757. Just after the victory in battle of Plassey in 1757 and the battle of Buxar in 1764, British obtained political control of the modern states of Bengal and Bihar (formerly Bengal Presidency). The British were formally granted revenue-collection rights in these areas in 1765. The present study shall analyse the historical background in two phases, pre-British and pre-independence period and post-independence period.

2.2.1. Pre-Independence Period

Land revenue was the main source of revenue traditionally to *Mughal* as well as to British. During the period of *Mughal* rule in the sixteenth and seventeenth centuries, land revenue was collected by non-hereditary, transferable state officials (the *Mansabdari* system introduced by Emperor Akbar). Land revenue, or land tax, was the major source of government revenue during British times as well. In 1841, it constituted 60 percent of total British government revenue, although this proportion decreased over time as the British developed additional tax resources. Not surprisingly, land revenue and its collection were the most important issues in policy debates during this period. Different arrangements of land revenue system or land tenure system were made by British to facilitate their collection of land revenue. These systems defined who had the liability to pay the land tax to the British. Up to a first approximation, all cultivable land in British India fell under one of three alternative tenural systems: (a) a landlord-based system (also known as *zamindari* or *malguzari*), (b) an individual cultivator-based system (*raiyatwari*), and (c) a village-based system (*mahalwari*). The revenue rates used to determine on fairly ad hoc grounds, based on a diverse set of factors, primarily based on soils and secondarily on consideration of the caste of the tenant, capabilities of irrigation, command of manure etc.

Legally the *zamindars* were considered to be the owners of the land. But in reality their role was that of government-appointed middlemen who collected revenue from the title-holders. Revenue used to be paid in cash to the government and it used to be major part of the revenue paid by the title-holders to the *zamindars,* who had the right to collect any amount of revenue as they wished from the title-holders. And then there were the title-holders at the second level who had obtained the right from the owners of the land or from other title-holders to collect revenue. At the third level there were the occupancy *raiyats* who used to pay revenue for the land they had occupied and cultivate the lands by themselves or with the help of the members of their family or by hired labourers or with the help of their partners. They could transfer their rights to someone else. Below them were the non-occupancy *raiyats* who had to pay revenue for occupying the land on a temporary basis. There were sub-tenants who had to pay revenue for getting land on a temporary basis from the *raiyats*. In the 30s and 40s, in Bihar, a flood of peasant movement was gushing forth. The main objectives in these movements were for *zamindari* abolition during the British raj (Jha, 1997).

Towards the end of 1938, the Government of Bengal appointed a land revenue commission to examine the existing land revenue system with reference to the Permanent Settlement. The commission submitted its report in 1940. Some serious defects of the *zamindari* system were pointed out. It was recommended by the commission that *zamindari* system should be abolished to improve the economic condition of the cultivators of lands and the Government should be brought into the direct relationship with the actual cultivators.

2.2.2. Post-Independence Developments in Land Policy

With assumption of office by the congress ministry in 1946 highest priority was given to the abolition of *zamindari* system of the state of Bihar. In this context, the Bihar State Acquisition of *Zamindaries* Bill, 1947 was drafted and introduced. The nomenclature of the bill was subsequently changed in the Bihar Abolition of *Zamindaries* Bill and was passed in 1948.

After independence, several states passed legislation in the early 1950s, formally abolishing landlords and other intermediaries between the government and the cultivator. Other laws have also been passed by different states at different times regarding tenancy reform, ceiling on land holdings, and land consolidation measures (Banerjee & Iyer, 2005). Bihar was the state where land reforms legislations were first brought in. In 1950s, just before the *zamindari* abolition, there were 2,05,977 nos. of regularly revenue-paying, permanently settled, holdings and they accounted for 90% of the land area. Bihar Land Reforms Act 1950 was amended and passed as the Bihar Land Reforms (Amendment) act 1953, making all intermediaries interests vested in the state with publication of the notification absolutely free from all encumbrances.

The process of abolition of *zamindari* completed in 1956, but before the abolition, proprietary interest in land was vested in the proprietors of the estate in which the land was comprised. The estates were of three classes as follows:

1. Permanently settled estates.
2. Temporarily settled estates
3. Government estates

The permanently settled estates used to belong to those estates, the proprietors of which took engagement with the East India Company to pay the land revenue demand assessed in accordance with regulation 1 of 1793 (generally known as Permanent Settlement Regulation). Temporarily settled estates were of two categories, firstly, these estates were the estates of those persons who for one reason or the other failed to take out engagement with the East India Company for payment of land-revenue demand assessed at the time, and secondly the estates which were held revenue-free on invalid or unjustifiable titles. The lands fall under category of government lands were (a) waste land, (b) *thanadari* land for police station, (c) lands escheated to Government in default of legal heirs or claimants, and (d) lands forfeited for any State offence.

- ***Zamindari* Abolition and Land Reform:** Bihar government passed the Abolition of *Zamindari* Act in 1947. In 1948, this was amended and published as Bihar Abolition of Zamindari Act, 1948. Bihar Land Reforms Act was passed in 1950. This act was also challenged and Patna High Court, declared the act contravening the article 14 of the constitution. Then a Bill called the Constitution Bill, 1951 (First Amendment) was introduced in the Parliament which *inter alia* provided for certain amendment to article 31 of the constitution (Government of Bihar, 1956).With this act the rights of *zamindars* and title-holders on land and at the same time trees, forests, fish-breeding ponds, markets, mines and minerals, were legally terminated. And these rights were directly vested with the state government. To break concentration of land holding in the hands of few, in 1955 the ceiling bill which is called Bihar Agricultural Land (Ceiling and Management) Bill was prepared, but could not be presented due to strong resistance and influence from prosperous landowners. In 1961 a revised version of the earlier bill - Bihar Land Reforms (Ceiling, Land Allocation and Surplus Land Acquisition) Act - was brought in. It is specified in this act that, any 'person' (not the family) cannot keep more than certain specified amount of land, depending upon the category of the land. All these efforts have been made to ensure equity in distribution of land in the state.

2.3. Land Tenure Typology in Bihar

Land Tenure system, as defined, is the relationship, whether legally or customarily, among people, as individuals or groups, with respect to land. It argues the land tenure system as an institution i.e., rules invented by societies to regulate behaviour. These rules of tenure define how property rights to land are to be allocated within societies. They define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. In simple terms, land tenure systems determine who can use what resources for how long, and under what conditions (Food And Agriculture Organisation, 2002). The concept of 'tenure' is a social construct that defines the relationships between individuals and groups of individuals by which rights and obligations are defined with respect to control and use of land (Economic Commission for Africa, 2004). In this line, section 5(1) of the Bihar Tenancy Act, 1885 defines tenure holder as primarily a person who has acquired from a proprietor or from another tenure-holder a right to hold for the purpose of collecting rents or bringing it under cultivation by establishing tenants on it, and includes also the successors in interest of person who have acquired such a right. Here the tenure means the interest of a tenure holder or under tenure holder. The tenure may be classified as follows:

1. Tenures derived from ancient rights;
2. Tenures which arose from the desire of the *zamindar* to improve his estate by extending his income and at the same time, to divest himself of the trouble and responsibility of direct management.

There is no reliable record as to its origin. Some of these might have been distinctly created by the *zamindar* after the Permanent Settlement; others existed from before that date.

For the purpose establishing and ensuring rights over land and between landlords and tenants as well to resolve disputes, the Bihar Tenancy Act, 1885 has defined tenants in following three categories.

1. Occupancy *raiyats.*
2. Non-occupancy *raiyats.*
3. Under *raiyats.*

Occupancy *raiyat* is a person having a right or occupancy in the land held by him and who holds any land suitable in a village for twelve years either himself or through inheritance, becomes a settled *raiyat* of that village, such a *raiyat* gets rights of occupancy in all lands for the time being held by him as *raiyat* in that village. Non Occupancy *raiyat*, on the other hand, does not have such right of occupancy over land. The under *raiyats* are those who holds tenancy immediately or mediately under a *raiyat*. These under *raiyats* are share croppers, whose establishment of tenural rights and security needs attention.

3. TENURE SECURITY: THEORETICAL FRAMEWORK AND STATUS IN BIHAR

3.1. Land Tenure Security and Property Right: Theoretical Framework

A proper functioning of land market is very important for the overall development of the economy. If there is gap in access of land by farmer, it would them to leave agricultural activity and to move to other activities, which in turn create situation that can be economically, politically and environmentally unpalatable. However, there is evident substantial inequality in ownership of land in different parts of the world. Another matter of concern is that, the property rights not well defined, especially of land (Roy, 1998, pp. 415-417). There is a close relationship between land tenure and property rights. It is argued that, this tenural right affect economic growth in a number of ways. As Deininger (2003) defined that a secure property rights will increase the incentives of households and individuals to invest, and often will provide them with better credit access, something that will not only help them make such investments, but will also provide and assurance substitute in the event of shocks. Secondly, it has long been known that in un-mechanised agriculture, the operational distribution of land affects output, implying that a highly unequal land distribution will reduce productivity. Even though the ability to make productive use of land will depend on policies in areas beyond land policy that may warrant separate attention, secure and well-defined land rights are key for household asset ownership, productive development, and factor market functioning. The tenural right plays important role in shaping farmers' land-use decisions. The tenural right on land and ownership is vital for rural people, especially poor whose livelihood depend upon farming. The absence of tenural security and property right make the farmers insecure and force the farmer to concentrate on short term profit maximization at the cost of degradation of land for sustainable use (Tenaw, Zahidul Islam, & Parviainen, 2009). Even land-improving investments were significantly affected by ownership security, and also that ownership security enhances capital formation by providing better incentives and improved access to credit (Feder, Onchan, Chalamwong, & Hongladaron, 1988). In this regard, right of women in accessing land is another concern. The right over land makes women not only vocal in domestic decision making; it also makes them confident to participate in the development spaces. Literature suggests that women's ability to have independent access to and exercise control over assets is a critical determinant of their welfare and income earning capacity (Fatchamps & Quisum, 1995) has a significant and positive impact on food expenditure as well as on children's educational attainment (Katz & Chamorro, 2002; Haque, 2012). As women spend most of their personal income in children education and nutrition, right of the source of income of women actually foster human development. The female land ownership, as argued by Wiig (2013), contributes more to the common good of the household, which gives women a stronger voice through general norms of 'influence according to contribution' as emphasised by Sen (1990). It also empowers women with increased bargaining power (Agarwal, 1995). It is also found that, women with right over land are less vulnerable from domestic violence (Panda & Agarwal, 2005). Given this theoretical framework of importance of tenure security, the following section discuss about recognition of land right and tenure security ensured through legal framework and their implementation status in Bihar.

3.2. Recognition of Land Rights in Bihar

The Bihar Tenancy Act, 1885, deals mainly with respective rights and obligations of the state and tenants. Tenancy law primarily concerns with agricultural land, falling in rural areas. After the abolition of the zamindari (landlordism), the *raiyat* came into direct contact with the government. The government, being the ultimate owner of the land, became the landlord.

A *raiyat* means primarily a person who has acquired a right to hold land for the purpose of cultivating it by himself or by members of his family or by hired servants or with the aid of partners on a crop share basis. If somebody else is attached to agricultural operation under a *raiyat* on crop share basis, he will be called an under-*raiyat*. Section 48 C of the Bihar Tenancy Act, 1885 provides that if an under-*raiyat* has held land continuously for a period of 12 years under a lease or otherwise, shall acquire the right of occupancy on that land. Nonetheless, there is major shortcoming in this section. Its proviso says that no such occupancy rights shall accrue if the land held by the *raiyat* is less than 5 acres of irrigated or 10 acres of other land. By implication, the provision with regard to benefits accruing to under-*raiyats* including protection against ejectment are not available to vast majority of under-*raiyats*, who work under small and marginal farmers. As per agricultural census of 2010-11, 96.92 percent of the state aggregate of operational holdings were held by marginal and small farmers. By implementation of the provisions in regard to the empowerment of the under-raiyat working 96.92 percent marginal and small farmers are out of their pale. Area involved in operational holdings of marginal and small farmers comes to 76 percent. By implementation, under-raiyats substituting if any, 76 percent of the operational holdings in Bihar will be deprived of the benefit given by law especially with regard to security of land and tenure. Sharecroppers are one of the most vulnerable but important category in Bihar. Though, no data available, an estimated 15-20 percent of all cultivators working on farm land as oral sharecropper. Though there is law to prevent eviction of share cropper, but, there is hardly any law to protect and ensure their tenural right over the land they cultivate.

Regarding individual tenural right, though there are numbers of legal provision to protect, but due to absence of any systematic survey there are no updated data especially numbers of tenents in Bihar. However, reference here is made to section 48(C) of the Bihar Tenancy Act, 1885, whereby occupancy under-*raiyat* accrues to a share cropper if he has worked for 12 years as such. A further reference is made to section 48(D) of the Bihar Tenancy Act, 1885 whereby an occupancy under-*raiyat* can become an occupancy-*raiyat* of the plot held by him upon payment of 24 times of annual rent as compensation to the land holder. Here, the word ‘rent’ refers to the value of the produced share not the revenue rent that is payable to the government. The section 48(E) of the Bihar Tenancy Act, 1885 provides for protection to the share cropper against ejectment or threatened ejectment by the land holder. The share cropper in such cases can approach a Conciliation Board. Even though sharecropper rights are not formally recorded anywhere, the board can visit the spot and collect local evidence to reach at a conclusion. Regarding, recording and mapping of individual land in rural areas, the available land data are not updated. The survey operation for recording and mapping of land in Bihar was conducted in three phases. The cadastral Survey completed in 1922-25. The Revisional Survey started in the decade of 1960s but did not cover all the districts. It completed in 12 districts but took long time to complete. In 14 districts it started but partially covered. In 12 districts the revisional survey could not be started. State Government has passed Special Survey and Settlement Act, 2011 to conduct land survey with specialized modern technique and the special survey has just started. As record of rights on land is generally prepared through Survey, the lack of proper survey and updated land data and land map appear as hindrance to ensure legal right of the tenure holder. Since independence, the State Government has made efforts to create land rights for vulnerable and disadvantaged sections of the population. A positive result is the issuing of *Basgit Purcha* (homestead grant) to home-less families in Bihar under the Bihar Privileged Person Home Stead Tenancy Act, 1947. Under this act, eligible persons, who were attached with the household of a land holder doing domestic and agriculture chores to which the land lord allotted a portion of private land for homestead land thus formalising a customary system. The Bihar Privileged Persons Homestead Tenancy Act, 1947 also ensured provision in respect of homesteads held by certain class of persons in the rural areas. However, though there are numbers of legal provisions to ensure legal right of land, in Bihar, the enforcement and implementation of these acts are very poor. This causes ejectment or threatened ejectment of land owner from land, land grabbing and encroachment. This act was dormant in rural Bihar but operationalised in a campaign mode, under the Mahadalit Vikas Mission since 2009.

Even though, since independence, several initiatives in the form of Abolition of *zamindari*, land reform and land ceiling have been initiated to fair and distribution of land, yet the distribution pattern of land in Bihar shows highly skewed towards big land lords, who holds large chunk of lands. In Bihar, the Land Reform Act, 1950 passed to ensure legal right to cultivator and small farmer and to address the issue of concentration of land resource in single hand. The Bihar Land Reforms (Fixation of Ceiling Area and Acquisition of Surplus Land) Act, 1961 passed to provide for fixation of ceiling, restriction on sub-letting and resumption by certain raiyats, for personal cultivation of land. In this Act a person in place of family was provided to retain with themselves 20-30 acres of land depending on their category. Apart from this, they were also allowed to retain 10 acres of land as homestead area, 15 acres for growing fodder.

With land as a foundation, the rural poor will be better able to use the building blocks of education, healthcare, clean water, nutrition and access to credit to bootstrap themselves out of extreme poverty. Condition of women is even worse. Though around 17 crores of rural women work in agriculture and allied activities a major portion of them do not hold land. The Ministry of Rural Development, (Government of India, 2011) found that, in India, whereas 83% of rural women provide agricultural labour only 10% of rural land is actually titled to women. Several studies also pointed out this biased condition of rural women over land right.

3.3. Women Land Right in Bihar

Regarding, land right to women, the Amendment of Hindu Succession Act, 1956 in 2005 is land mark as it provides hindu women equal inheritance rights. In 2005 the Hindu Succession Act, 1956 was amended to give Hindu women equal inheritance rights to agricultural land and overriding the state tenurial laws. Daughters, including those married, also became copartners in joint family property. However, the implementation of these legal changes remains to be investigated on the ground. Lack of awareness on the part of women and Indian society about this law has emerged as constraints. The inheritance of property by Muslims is dictated by Muslim Personal Law (*Shariat*) Application Act of 1937. According to this Act, widows and daughters who are in the same relation as a male family member to the deceased, receive half the share of property received by the male family member.

Bihar traditionally an agrarian society with 88.71% of rural area also characterised with low level of female literacy of 46.40% and wide gender gap in the literacy rate which is 24.8%. There is high fertility rate in the state with decadal growth rate of 25.42%, coupled with decreasing sex ratio from 921 in 2001 to 918 in 2011, which is much less than national average of 940 (Census India, 2011). Though the 'Bodhgaya Movement' in which women demanded their right on land took place in Bihar in 1978, no such special initiative taken to improve condition of right over land to women. Except some recent initiative, through which transfer of land to weaker section recorded in name of female member of family, but there is no such legal provision to ensure women right over land . Regarding holding of title over land by women it is evident that, individually women hold 12.8% of total land in Bihar (table1). Probing deeper into it, it is found that there is an improvement in the ownership of women in land holding in recent years. This improvement is argued as the result of the recent policy changes in favour

Table 1. Ownership of land in Bihar

Particulars	Number of Holding	Area in Hectare
Individual		
Male	11948188 (86.33%)	4526324.93 (87.12%)
Female	1891472 (13.67%)	669055.73 (12.88%)
Total	13839660 (85.48%)	5195380.66 (81.34%)
Joint		
Male	1940631 (83.44%)	985013.86 (84.52%)
Female	385252 (16.56%)	180390.31 (15.48%)
Total	2325883 (14.36%)	1165404.17 (18.24%)
Institutional	25848 (0.16%)	26775.88 (0.42%)
Total	16191391	6387560.71

Source: Department of Revenue and Land Reforms, Government of Bihar of women (Samanta & Jha, 2014). However, individually as well there is no legal provision to ensure women right over land. Land reform and land ceiling are initiatives to address the issue of equity in distribution of land and resist concentration of land in one hand.

4. SUSTAINABLE DEVELOPMENT AND TENURE SECURITY: AN ASSESSMENT IN THE CONTEXT OF BIHAR

Sustainable Development, defined by the World Commission on Environment and Development, 1987, as the development which meets the needs of the present without compromising the ability of future generations to meet their own needs. However, there has been a growing recognition of three essential aspects of sustainable development, as defined by Harris (Harris, 2003).

- **Environmental:** An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems or environmental sink functions, and depleting non-renewable resources only to the extent that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources.
- **Economic:** An economically sustainable system must be able to produce goods and services on a continuing basis, to maintain manageable levels of government and external debt, and to avoid extreme sectoral imbalances which damage agricultural or industrial production.
- **Social:** A socially sustainable system must achieve fairness in distribution and opportunity, adequate provision of social services including health and education, gender equity, and political accountability and participation.

Given this framework of sustainable development, the present study tries to view the situation of Bihar from the perspective of land tenure security. From the environmental sustainability context, there is no change in forest coverage in Bihar during 2003-2010. In Bihar notified forest area is 6473km^2. Out of this forest area 692.89km^2 is categorised as reserved forest and 5798.89 km^2 is classified as protected forest (Environment and Forest Department, Government of Bihar). Regarding tenural right, local dwellers are entitles for right and privilege as mentioned in the *Khatiyan* (Register) of land of protected forest. Users' rights on key natural resources on land (including fisheries) are legally recognized and put up in practice in the protected forest area. The usufructuary rights of users on natural resources and forest produce also recognized in Bihar. Usufructuary rights referred to the right of individual or community to use and enjoy property of another, provided its substance is neither impaired nor altered. The Joint Forest Management Committees also instrumental for ensuring these rights. The situation is quietly different for national parks / wildlife sanctuaries; as there is no users' right in 13 national parks / wildlife sanctuaries in Bihar. These parks / wildlife sanctuaries come under the broader category of reserve or protected forest as the case may be. They have been classified based on concept of management of forest. The national parks / wildlife sanctuary are governed by the Wildlife Protection Act, 1972. To ensure right of the forest dweller, Government of India in the year of 2006 enacted Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006, popularly known as Forest Right Act (FRA) and Tribal Land Act. The law concerns the rights of forest-dwelling communities to land and other resources, denied to them over decades as a result of the continuance of colonial forest laws in India. The Act, which inherently recognises that a healthy ecosystem is compatible with social justice technically, holds precedence over all other forest and wildlife-related laws. Although its provisions for restoring the rights of forest-dependent households may not cover all rights deprivations they hold the promise of improving the lives and livelihoods of more than 100 million of India's poorest citizens. However, it is important to remember that the FRA is only an enabling legislation, where the implementation of it with true letter and spirit appeared as challenge in Bihar.

Bihar has common land in the state. The local nomenclature of common land in Bihar is '*Gairmazruha Aam'* which is common land and is basically community land, owned by the village community. These include grazing land, village pathways, village waste land, play grounds, orchards, cremation, and burial places. Even if the nature of these land have changed over a period of time (if a tank is filled up), the consent of the *Gram Sabha* (body of village Local Self Government) will be mandatory for the Government to put that land into some other use or to be settled or to be distributed to the weaker section of the society. With a view to regulate the conversion of agricultural land to non-agricultural purposes, Bihar Agriculture Land (Conversion for Non-Agricultural Purposes) Act, 2010 was enacted as Bihar Act 11 of 2010, however, no condition regarding environment and ecological imbalances has, even categorically, been mentioned in the Act to restore environmental balance. There is a need to include provision to protect environment and ecology in the state. However, secure land tenure and resource rights argued to be key drivers of bio-diversity and sustainable natural resource management. It is also argued that the lack of proper definition of rights can degrade the natural resource and ecosystem, as the insecurity shall lead to overgrazing of pastureland, poaching of wildlife, deforestation, ineffective watershed management, and poorly planned extractive industry investments (USAID).

Equity, especially intergenerational equity has been identified as central ethical principle of sustainable development (Bender, 2000). The importance of equity in sustainable development also recognised by United Nations Conference on Environment and Development (UNCED) in the Earth Summit at Rio in 1992 as the agenda 21 of the Rio Declaration put forward that "Equity derives from a concept of social justice. It represents a belief that there are some things which people should have, that there are basic needs that should be fulfilled, that burdens and rewards should not be spread too divergently across the community, and that policy should be directed with impartiality, fairness and justice towards these ends." The World Commission on Environment and Development commonly known as Brundtland Commission, whose mission was to unite countries to pursue sustainable development together, also has given high priority to poverty alleviation and equitable development and argued for equitable distribution for constrained resources (Lele & Jayaraman, 2011). In regard to social sustainability of distribution of land, several acts and laws have been passed in Bihar since independence to ensure equity in distribution of land. Bihar is the pioneering state to Land Reform initiative and passed in the year 1950 the Bihar Land Reform Act, 1950. After this other initiative like passage of Bihar Bhoodan Yagna Act, 1954 and through Land Ceiling Act (Bihar Land Reforms (Fixation of ceiling area and acquisition of surplus land) Act, 1961 have been taken to restore distributional equity in land. However, the ground reality depicts different picture in regard to distributional equity. The National Sample Survey Organisation's (NSSO) Survey Report No 491, 2003, reveals that marginal and small farmers, who constituted 96.5% of the total landowning community in Bihar owned 66% of land. Medium and large farmers who constituted only 3.5% of the total landowning community owned 33% of the land. Of the latter, the large owners (constituting only 0.1% of the total) own 4.63% of total land. In absolute terms, this 0.1% of the large owners owned a little over 8 lakh hectares or 19.76 lakh acres of land. This concentration of land resource in hand of very few persons creates distortions in achieving equity in sustainable development.

There are several initiatives by state government to provide homestead land to homeless people and enhance livelihood opportunity by distributing land from different sources, like ceiling surplus land, land received under Bhoodan Yagna Act and public land suitable for distribution (Table2). Yet the problem with this novel initiative is dispossession and threatened dispossession and land grabbing. Although the land is allotted to landless people of the state, the major problem is giving them possession and legal entitlement. Dispossession has been reported in number of cases. Nearly 1 lakh dispossession is in case of Bhoodan land reported. Tackling the issue of giving possession and restoring disposed land to the actual beneficiaries appeared as challenges to the government to address social aspect of sustainable development.

Table 2. Public land distributed to landless beneficiaries till 31st March, 2013

Type of Land	No. of Beneficiaries	% of Beneficiaries
Bhoodan	2,92,616	
Ceiling surplus	3,50,374	
Gairmazruha Aam	43,710	
Gairmazruha Khas/*Malik*	10,45,030	
Basigat Parcha	5,80,214	
Total no. of beneficiaries	23,11,944	
Possession given	20,94,439	90.6
Mutation done	18,68,304	80.8
Rent fixation done	13,71,196	59.3
Enter in Jamabandi	19,13,561	82.8

Source: Department of Revenue and Land Reforms, Government of Bihar

Tenural security towards land has far-reaching and long lasting socio-economic implications. While secure tenural right is said to influence efficiency and investment in land as well as acts as a precondition to environmentally sustainable land use. Since the inception of the Bihar Tenancy Act, 1885, concerted efforts have been made to protect the land tenure rights of the tenants. However, not much change has been in sight, be it in land tenure rights or in the protection of sharecroppers. This lack of tenural right, theoretically, paves way for two problems towards sustainable development; in one hand it restrict the sharecropper to undertake a long term investment in the land to increase productivity, on the other hand this might have created the problem termed as 'tragedy of commons' propagated by Hardin (Hardin, 1968). These causes inefficient use and lack of stewardship over the use of land, affect the sustainable development of livelihood. Garret Hardin used the example of a pasture and a group of shepherds who graze their sheep in the pasture to illustrate the problem termed as 'tragedy of common' to point out that 'rational economic decisions' by each shepherd would lead to overgrazing of the pasture, which leads to degradation of common property resources as well environmental loss. The non-specificity of tenural rights may paves way to environmental degradation. The lack of tenure security brings up lack of stewardship on the land. It has well recognised that and securing rights over land and natural resources fosters stewardship. When individuals, communities and other groups, and legal entities have secure rights to land and resources, incentives shift in positive directions. Secure land and resource rights provide people with incentives to conserve resources because they are better able to capture future investment returns. Strengthening land and resource rights and improving enforcement capacity can help conserve natural resources as well as improve livelihoods (USAID). Property rights have been identified as the key for conservation and sustainable use, management and governance of land and other resources (Aggarwal & Elbow, 2006). It is also argued that insecure, unclear, limited or short-term property rights can inhibit sustainable land and natural resource management and discourage stakeholders from acting as long-term stewards of land and natural resources. While Hardin provided the solution through privatisation or government control, the collective agreement and enforcement by the resource users themselves through well-designed institutional arrangements proposed by Ostrom et. al (1999) for sustainable use of common resources (Ostrom, Burger, Field, Norgaard, & Policansky, 1999; Lele & Jayaraman, 2011).

5. IMPLICATION AND CONCLUSION

Land Tenure system is the relationship, whether legally or customarily, among people, as individuals or groups, with respect to land. The rules of tenure define how property rights to land are to be allocated within societies as well as define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. When resource tenure and property rights are insecure, the potential for sustainable resource management is undermined. Secured tenural right over land found as influencing factor in utilising the land in more efficient way, do investment as well as precondition for environmentally sustainable natural resource use. However, the land tenure system, both statutory and customary, is under threat of global demographic growth, growing food scarcity and environmental degradation. It has appeared as challenge to government as land tenure security is precondition for access to other services and livelihood opportunities. Bihar, a backward state in India also face the challenge as the distribution of land is quite skewed in the state. Several attempts, like passage of Land Reform Act, Zamindari Abolition Act, Land Ceiling Act etc. have been made to ensure equity in the land distribution. The study found that there since independence Bihar has taken proactive measures to ensure legal land rights over land of individuals in rural and urban areas through legal provisions and enactment of a large number of Acts and Rules. However, the areas of concern are deficient implementation of Acts / rules, non-completion of revisional survey, poor availability of Record of Rights (RoR) to ensure legal right of tenants, un-updated record of rights, lack of proper legal net to safeguard sharecropper. When, a proper functioning of land market is very important for the overall development of the economy, he land market in Bihar is imperfect as there is lack of proper data on record of right and improper pricing of land. There is recognition of individual land rights in both urban and rural areas as well as house sites and land for production were allotted for equity purposes to weaker section. However, the proportion of land in the name of women is very less, even if several recent initiatives to do so. One of the biggest problems in Bihar is outdated land records which have little relevance with the ground reality; which appears as constraint to ensure land right another is absence land use policy. A large amount of public lands under different categories have been distributed amongst weaker sections for providing housesites and support livelihood. However, giving possession to these lands appears as challenge. As distributional equity, especially intergenerational equity has been identified as central ethical principle of sustainable development, the lack of tenure security affect conservation and sustainable development. Secure land tenure and resource rights argued to be key drivers of bio-diversity and sustainable natural resource management and insecurity may lead to degradation of natural resources. Though there is no significant change in forest coverage in Bihar in last few years, but there is a steady erosion of village commons/common property resources. However, the law restricts settlement of common property resources unless there is change in the nature of land and the *gram sabha* (village constituency) consented for that.

Even after several initiatives, the land distribution found to be very much skewed against the poor and marginal farmer. Lack of proper tenural right of share cropper reduce stewardship of the land and may invite the problem termed as 'tragedy of commons' which leads to degradation of common property resources as well environmental loss. As secure land and resource rights provide people with incentives to conserve resources because they are better able to capture future investment returns the study argues for proper legal framework and implementation to protect land tenure security for increase productivity, address the problem of 'tragedy of commons' and ensure sustainable development

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Chapter 18
Adaptation to Climate Change for Sustainable Development: A Survey

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ABSTRACT

Climate change is an important global issue. For sustainable development human society must adopt the climate change and reduce vulnerability. This chapter provides an overview on the climate change and its effects, in response how human societies adopt it across the globe. Chapter reviews major papers on adaptation to climate change. Based on major important articles this chapter provides clarity of the concept of adaptation, types of adaptation, measurement of adaptation and determinants of adaptive capacity. It also highlights on sustainable development and shows possible future directions of adaptation and limitations.

1. INTRODUCTION

Climate change is the most severe problem that we are facing today. Climate change is one of the greatest threats to the human civilization and the toughest challenge for the economic development in the 21st century. Accumulation of fossil fuel consumption in developed countries during industrialization is the main cause of climate change in the world. They have contributed a lot to change the climate. Less Developed Countries (LDCs) have contributed negligible or little to cause climate change, yet face its harshest impacts and have the weakest capacity to adapt to these impacts. This chapter reviews adaptation and sustainability issues under climate change conditions. In this context, even there is lot of limitations or obstacles for development; adaptation to climate change minimizes risks and also provides certain opportunity to grow with sustainable development. There are more than thousand research articles on climate change, adaptation, and sustainable development but I shall cover few important papers and try to provide a clear concept on it.

This paper is organized as follows. Section 1 highlights climate change and its impacts. Section 2 clearly defines the concept of adaptation, nature of adaptation, measurements, cost, etc. Section 3 briefly describes adaptive capacity. Section 4 reviews sustainable development. Section 5 presents future adaptation and finally, Section 6 concludes.

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2. CLIMATE CHANGE

Climate change is real, and the causal link to increased greenhouse gas emissions that is now well established (Coondoo and Dinda 2002). Globally, the ten hottest years on record have occurred since 1991, and in the past century, temperatures have risen by about 0.6^0 C (See, IPCC reports for details). In the same period, global sea level has risen by about 20 cm – it is partly due to melting of mountain ice and partly due to thermal expansion of the oceans. Scientific research finds evidences that in last two centuries anthropogenic activities have increased atmospheric greenhouse gases concentration that is more than pre-industrial levels. Only increasing pressure of greenhouse gas emissions and aerosol concentrations in atmosphere could explain the rising trend in temperature in last 100 years (IPCC reports).

Recent climate change is the result of human actions and specially from the burning of fossil fuels and land use changes. Development activities increase the atmospheric concentrations of greenhouse gases (GHG) – mainly carbon dioxide, methane and nitrous oxide. The GHGs are accumulated in the upper level of atmosphere and acts like the roof of GHG that is tapping solar long-wave radiation which raises temperature. It also provokes other forms of climate disruption and accelerates the process. This depends on a complex interplay of many factors, including rates of population expansion, economic growth and patterns of consumption. The effects are not uniform. The changes differ from one location to another. There are different weather consequences, while some regions have intense rainfall, others have more prolonged dry period and few areas have both.

2.1. Treats of Climate Change

As a consequence of continued global warming, millions and millions of people around the World are facing risk of flooding, droughts and debilitating diseases like Malaria, Dengue, Swine Flu, Chickengunia, Encephalitis, etc. Poor people in under developed nations are likely to be most vulnerable in health and their livelihoods. The social consequences also vary and it depends on level of development. There are different social impacts within the same society – heat stress affects older people more than young. Across the world and in every country those most at risk are typically the poor, and in developing countries those who depends most for their survival on a healthy natural environment, such as ethnic tribes, fishing communities, and livestock herders. There is still good chance of mitigating the bad effects of climate change through stabilizing atmospheric carbon dioxide concentration relatively at lower level which can be achievable target.

Taking action to tackle the climate change may provide better standard of living and may also create economic opportunity in terms of job creation or employment opportunity. We need to investigate all means of reducing atmospheric carbon dioxide concentration like sequestration, fusion, fuel cells, renewable energy, etc. Climate change is causing the earth's surface temperature to rise and increasing the prospect of extreme weather events. To some extent this affects everybody, but it is difficult to predict climatic event at a specific location and at particular point of time. It is certain that people living in fragile and difficult ecosystems become more vulnerable with risks to their health, their livelihoods. It is possible to adjust to most of these changes and to protect those most at risk.

2.2. Action for Adaptation

Already the World has considerable experience of many types of adaptation and knowledge that can fruitfully be shaped both within and between countries. The important lesson is that many measures are essentially social and political – people living in poor housing conditions, or living from small plots of land with poor soil and little water, have always suffered most from climatic extremes. The remedies are difficult but technologically they are relatively straightforward. Adaptation requires the application of technology. It is clear that all countries should devise national strategies for adaptation, assessing the communities, risk and planning appropriately. This is becoming urgent need of the civilized human society.

The quality of today's decision-making on agricultural or industrial development or on the layout of towns might be tested against future variations in climate. A new climate is on the way and adaptation is no more choice, it is a necessity. Several studies observed impacts of climate change on ecological system over the last several decades (Parmesan and Yohe (2003), McCarthy et al. (2001)). The Earth system faces irreversible due to change in mean climatic conditions. Along with changes in climatic conditions the earth faces sever catastrophic events and that will cause huge damage of natural productive capital in the economy. Societies and individuals have to adjust their behaviour in response to past climatic changes. People are contemplating adapting to altered future climatic conditions. These adapting actions are sometime reactive that are based on current assessments, it is also anticipatory. There are several factors that motivate individuals and society to adapt climate change for protecting economic well-being or reducing risk related to climate change.

Adaptation can be motivated for improvement of safety and that is possible through market exchanges (Smit et al. 2000) and expansion of social networks. Adaptation is an issue relevant at local, national and international levels. Success of an adaptation strategy depends on its objectives that affect the ability to meet adaptation goal. Success of adaptation depends on scale of implementation and the criteria used to evaluate it at each scale. So, it is necessary to clarify the concept of adaptation and review adapting agents of climate change.

3. ADAPTATION TO CLIMATE CHANGE

3.1. Conceptualisation of Adaptation to Climate Change

Adaptation is an adjustment in non-normal condition, which is created or regenerated due to several reasons – climate change is one of them. Adger and others, in their several papers, provide few definitions and finally a concept of adaptation emerges in the context of climate change effects. So, adaptation to climate change is an adjustment in socio-economic or/and ecological systems in response to impacts of climate change. Adaptation is the adjustment or change of traditional practices for non-declining wellbeing due to climate change effects. Truly, adaptation refers to changes in practices, processes, or restructures to minimise or offset potential damages associated with changes in climate. Adaptation involves adjustments to reduce the vulnerability of communities, or society, or regions, or nations. Adaptation to climate change is important for us because of (a) assessment of impacts and vulnerabilities, and, (b) development and evaluation of response options. It is important to know the vulnerability and find out the possible solution for it. So, the understanding expected adaptations are essential to impact and vulnerability assessment that is a fundamental base to estimate the costs or risks of climate change. Adaptation is considered an important *strategy*. Development of planned adaptation strategies to deal with risks is regarded as a necessary complement to mitigation actions. Human society formulates and implements to facilitate adequate adaptation to climate change. Truly, human society promotes and facilitates adaptation and deploys adaptation technologies to address climate change.

3.2. Nature of Adaptation

Adaptation is both to the *process* of adapting and to the *condition* of being adapted. The term, *adaptation*, can be interpretive or has specific interpretations in particular disciplines. In the social sciences, adaptation refers to adjustments by individuals and the collective behaviour of socioeconomic systems for their survival or for sustainable development in long run, where as in ecology, adaptation refers to changes by which an organism or species becomes fitted to its environment.

3.2.1. A Process

Adaptation is a process for a given condition. Adaptation is a relative term; it involves an alteration in the system of interest to the climate related stress. Description of an adaptation requires specification of who or/and what adapts, the stimulus for which the adaptation is undertaken, and the process and form it takes (Downing *et al.*, 1996; Feenstra et al., 1998).

3.2.2. Conditional Adaptation

The climate change-related adaptations are not limited to changes in average annual conditions; they include variability and associated extremes. Climatic conditions are inherently variable over time. Variability goes along with climate change. Adaptation to climate change necessarily includes adaptation to variability (Smit *et al.*, 1999). Other term *climate hazard is* used to capture those climate stimuli, in addition to changes in annual averages, to which the system of interest is vulnerable. In general, changes in the mean condition commonly fall within the coping range, whereas many systems are especially vulnerable to changes in the frequency and magnitude of extreme events or conditions outside the coping range (Kelly and Adger, 1999).

3.2.3. Coping

Many social and economic systems—including agriculture, forestry, industry, human health, and water resource management—have evolved to accommodate some deviations from normal conditions. The capacity of systems to accommodate variations in climatic conditions from year to year is captured in the coping type and range. This capacity also is referred to as the vulnerability or damage threshold. The coping range, which varies among systems and regions, need not remain static. The coping range itself may change reflecting new adaptations in the system (Smit *et al.*, 2000). The coping range can be regarded as the adaptive capacity of a system to deal with current variability. Adaptive capacity to climate change would refer to both the ability inherent in the coping range and the ability to move or expand the coping range with new or modified adaptations. Initiatives to enhance adaptive capacity would expand the coping range.

3.3. Adaptation Types

Adaptation *types* have been differentiated according to numerous attributes. Major distinctions are purpose or objectives and, time and space. Spontaneous adaptations are considered to be those which take place—invariably in reactive response to climate change without the intervention of a public agency. Estimates of these autonomous adaptations are used in impact and vulnerability assessment. Planned adaptations can be either reactive or anticipatory. Adaptations can be short or long term, localized or regionalized, and they can serve various functions and take numerous forms. Adaptations have been distinguished according to individuals' choice options. The choice pattern has been extended to include the role of community structures, institutional arrangements, and public policies (Downing *et al.*, 1996; Feenstra et al., 1998).

3.3.1. Classification Base

Adaptation can also be *classified on the basis of purpose, mode of implementation or institutional structure*. Adaptation is a continuous stream of activities, including to actions, decisions and attitudes. It helps to form decisions about all aspects of life that reflects existing social norms and processes. Adaptations are not isolated from other decisions, but occur in the context of demographic, cultural and economic change as well as transformations in information technologies, global governance, social conventions and the globalising flows of capital and labour. It can be difficult to separate climate change adaptation decisions or actions from actions triggered by other social or economic events.

3.3.2. Non-Climatic Driving Factors

Adaptations can also arise as a result of other *non-climate-related social or economic changes.* One householder decides to move from an increasing risk area to an area at lower risk. The movement of this household may not be primarily motivated by climate change, but rather by other demographic or economic factors. If this movement is due to, say, increasing risk of flooding, that may be connected with climate change. Irrespective of motivation for adaptation, both purposeful and unintentional adaptations can generate short-term or long-term benefits, but they may also generate costs when wider issues or longer timeframes are considered. Adaptations may amplify the impacts of climate change by ineffectual and unsustainable anticipatory action, as can be seen in the changing demand for air conditioning in cars and homes following a series of hot summers. Adaptations to non-climate drivers can increase vulnerability to climate change stress. More recent awareness of the heightened flood risk associated with living in flood prone areas may change the price signals that currently place a premium on coastal or riverside properties. The success of climate related adaptation actions may be negated by reactive adjustments by economic actors and it is a part of the process of continual adjustment to social and ecological change driven by multiple factors.

3.4. Goals of Adaptation

Objectives of actors and action processes focus on goals of adaptation. Action is interconnected with the scale and decision-making unit. Understanding the scale and unit of adaptation decision-making reveals the diverging goals of adaptation to climate change. These goals will differ within a sector, a society, between nations and, most intractably, between different generations. However, the goals of adaptation are not clearly stated explicitly. For some agents adaptation concerns conservation of status quo, while for others the current situation is undesirable and hence adaptation is about progress. The goal of adaptation will likely depend on who or what is adapting. Developed institutions and wealthier societies or individuals may seek to maintain their current state or standard of living through adaptation, whilst developing countries may be aiming to continue developing and enhance the standard of living of their citizens. For those on the margins of society, the immediate priority will be to secure their livelihoods or protect their assets from climate change effects and other risks. In ecosystems, successful adaptation is demonstrated by survival of the species in a changing environment, but not necessarily the survival of an individual. These divergent goals for adaptation emerge from different attitudes to risk to disposition, and to the adaptive capacity of future generations. There is a variation due to optimistic or pessimistic views of individuals, or community, or society or nation.

3.4.1. Risk Management

The risk management literature focuses on adaptation to natural hazards, including both climate and non-climate related hazards. Adaptations, adjustments or coping strategies are used to respond to the perceived risk of, or experienced impact of, a hazard. Burton et al. (1993) have classified these strategies as *share the loss, bear the loss, modify the events, prevent the effects, change use or change location*. These various strategies reveal different objectives of adaptation, although the overarching goal remains that of reducing the negative effects and increasing any benefits resulting from a hazard. Within the context of the climate change debate, the purpose of adaptation is often seen as to reduce vulnerability or to enhance resilience to climate change and climate variability (Smit et al. 2000). Other perspectives on adaptation are related to sustainable development.

Adaptation can be viewed as providing broader benefits, not just specifically to cope with climate impacts but as part of the development process. The resilience approach, as applied to linked social and ecological systems, views learning and adaptation as important processes that improve system resilience to a range of shocks, achievable through adaptive management (Folke 2006; Nelson et al. 2007). Adaptation actions can be used either to build resilience to prevent collapse of a system or to reorganise the system and recover once a shock has caused a collapse. There are trade-offs between the goals of building resilience and reducing vulnerability. Adaptive management approaches that promote resilience seek to learn from failure and promote the ongoing structures and functions of overall systems.

Vulnerability approaches focus on the most endangered individuals or ecosystems and seeks adaptations that protect those, perhaps at the expense of robustness and resilience of the overall system (Eakin et al. 2009). Hence there are a range of possible goals of adaptation. The choice between them is taken by institutions of collective response based on the underlying values of society.

3.5. Decision Making Agents

Adapting to climate change involves making decisions across a landscape made up of agents from individuals, firms and civil society, to public bodies and governments at local, regional and national levels, and international agencies. As mentioned above, a broad distinction can be drawn between action that often involves creating policies or regulations to build adaptive capacity and action that implements operational adaptation decisions. The latter will often be constrained and influenced by a higher-level adaptation framework as well as the institutions that define all aspects of activity in that society. For both public and private agents, where objectives of adaptation are explicit, they are often diverse.

Actions associated with building adaptive capacity may include communicating climate change information, building awareness of potential impacts, maintaining well-being, protecting property or land, maintaining economic growth, or exploiting new opportunities. The objectives associated with implementing adaptation decisions are more likely to focus on reducing the cumulative impacts of climate change, ensuring that adaptive measures taken by one organisation do not adversely impact upon others, avoiding anticipated adverse impacts of climate change, and ensuring that the distributional impacts of adaptation are minimised. Adaptation occurs without explicit recognition of changing risk, while other adaptations incorporate specific climate information into decisions. Unintentional adaptation may reduce the effectiveness of purposeful adaptation. Hence, the integration of adaptation actions and policies across sectors remains a key challenge to achieve effective adaptation in practice.

3.5.1. Adaptive Decision Strategy

Classifications of purposeful adaptations based on objectives of adaptation strategies frequently focus on measures which share the loss, bear the loss, modify the event, prevent effects, change use or change location (Burton et al., 1993). This classification is an expansion of the three cornerstones of adaptation: (i) reduce the sensitivity of the system to climate change; (ii) alter the exposure of the system to climate change; and (iii) increase the resilience of the system to cope with changes.

Increasing the resilience of social and ecological systems (Adger, 1999; Tompkins et al 2005) can be achieved through generic actions which not only aim to enhance well-being and increase access to resources or insurance, but also include specific measures to enable specific populations to recover from loss. The spatial scale over which these three dimensions of adaptation can be implemented varies, as does the role of international and national policy, individual and collective action. All dimensions of adaptation can be implemented at any scale.

3.5.2. Scale and Agency

In general, efforts to improve the ability of whole populations to recover from loss are more often tackled through public policy intervention at national level. Individual action will be adequate and specific public policy intervention may not be required to generate individual benefits from adaptation, although the adaptation actions are clearly reliant on permissive regulatory frameworks. This implies an appreciation of the nature of the operational, managerial or strategic decision that is at stake. This in turn requires the scale and agency of decision-making to be defined. Understanding the values that drive an adaptation decision is usually easier for decisions made at the micro-scale and by well-defined agents than at the macro-scale and by diffuse agents. This perspective also requires some appreciation of the differences between adaptation decisions seen as private or public. The values that are brought to bear on adaptation decisions become more diverse and contradictory as one moves from small-scales and single agents to larger scales and multiple agents. If one of the roles of government is to resolve conflicts between agents to engender collective action, then the importance of governance in adaptation decisions becomes increasingly important as one moves along this continuum (Cash et al. 2006). Adaptation decisions taken today may impose negative environmental and social impacts on a future generation. The values of future generations are most often explicitly incorporated into today's decisions through formal discounting methods in economics. But issues around critical natural capital, the non-material aspects of choice and culture, are effectively excluded from economic analysis.

The dependency of adaptation decisions on scale and agency may point to hidden limits to adaptation in an increasingly complex and interconnected society. Sobel and Leeson (2006) suggest that the impacts of Hurricane Katrina on New Orleans may be an example of complexity leading to failure. Here society was exposed to an environmental shock, to which it's weakening ability to resolve or reconcile divergent values through a complex governance structure induced catastrophic failure.

Climate change has significant impacts on development, poverty alleviation and other social security, and new threats emerges to water and food security, agricultural production, public health. Countries or regions that fail to adapt contributes to global insecurity through spread of disease, and a degradation of the economic system. Considering adverse impacts of climate change, adaptation is an integral component of an effective strategy to address climate change along with mitigation. The World's poor, who have contributed the least to the greenhouse gas emissions, will suffer the worst impacts of climate change and have the least capacity to adapt.

Adaptation is about building resilience and reducing vulnerability. It is not simply a matter of designing projects or putting together lists of measures to reduce the impacts of climate change. A national policy response should be anticipatory, not reactive, and should be anchored in a country's framework for economic growth and sustainable development, and integrated with its poverty reduction strategies.

The global climate is changing and will continue to do so even if greenhouse gas emissions are dramatically curbed. Therefore, countries face the challenge of adaptation to climate change. Developing countries are highly sensitive and vulnerable to climate change. There remains much to learn about the optimal adaptation. The best way to adapt to climate change is simply to focus on traditional growth and developmental goals with climate-proofing productive capital. Millner and Dietz (2011) model the task of apportioning investment between productive capital and adaptation to climate change. The scale and composition of productive and adaptive capital investments depend on empirical context. It is optimal to invest in adaptive capital over the coming years. Adaptations occur in the *system of interest*, *unit of analysis*, *exposure unit*, *activity of interest*, or *sensitive system*.

3.5.3. Intervention Strategy

In *unmanaged natural systems,* adaptation is autonomous and reactive and is the means by which species and communities respond to changed conditions. Human system adaptation can be motivated by private or public interest. *Private* decision makers include individuals, households, businesses, and corporations; *public* interests are served by governments at all levels. The roles of public and private participants are distinct but not unrelated. Planned adaptation often is interpreted as the result of a deliberate policy decision on the part of a public agency, based on an awareness that conditions are about to change or have changed and that action is required to minimize losses or benefit from opportunities. Autonomous adaptations are widely interpreted as initiatives by private actors rather than by governments, usually triggered by market or welfare changes induced by actual or anticipated climate change. Smith *et al.* (1996) describe autonomous adaptations as those that occur *naturally*, without interventions by public agencies, whereas planned adaptations are called *intervention strategies*. The extent to which society can rely on autonomous, private or market adaptation to reduce the costs of climate change impacts to an acceptable or non-dangerous level is an issue of great interest. Autonomous adaptation forms a baseline against which the need for planned anticipatory adaptation can be evaluated.

Distinguishing among the various decision makers involved in adaptation is important. The case of African agriculture and water resources illustrates that stakeholders and potential adapters range from vulnerable consumers to international organizations charged with relief and research. Poor and landless households have limited resources, yet failure to adapt can lead to significant deprivation, displacement, morbidity, and mortality. Subsistence farmers do not have the same adaptation options as commercial producers. Water supply adaptations may involve landowners, private traders, local authorities, water-dependent businesses, national governments, and international organizations. Each stakeholder has distinct interests, information, risks, and resources and hence would consider distinct types of adaptive responses (Downing *et al*., 1996).

3.6. Processes and Evaluation of Adaptations

In order to predict autonomous adaptations and provide input to adaptation policies, there is a need for improved knowledge about processes involved in adaptation decisions. This knowledge includes information on steps in the process, decision rationales, handling of uncertainties, choices of adaptation types and timing, conditions that stimulate or dampen adaptation, and the consequences or performance of adaptation strategies or measures (Rayner and Malone, 1998; Smit *et al*., 2000).

Decisions regarding adaptations can be undertaken at any of several scales, by private individuals, local communities or institutions, national governments, and international organizations. Where these adaptations are consciously planned activities, whether by public agencies or individuals, there is an interest in assessing the performance or relative merits of alternative measures and strategies. This *evaluation* can be based on criteria such as costs, benefits, equity, efficiency, and implementation ability.

3.6.1. Analysis of Adaptations

Adaptive behaviours provide information on the processes, constraints, and consequences of adaptations. Knowledge of the processes by which individuals or communities actually adapt to changes in conditions over time comes largely from analogy and other empirical analyses (Smit *et al*., 2000). Conceptual models of adaptation processes describe sequential relationships and feedback involving climate change. The contributions of spatial analogy are limited. Case studies document adaptive responses to climate change in resource-based economic sectors and communities over periods of several decades. Other empirical analyses have examined adaptive behaviour in key sectors such as agriculture in light of climatic variability and extremes over even shorter time periods. These direct empirical analyses of adaptation processes tend to start with the system of interest, then, assess its sensitivity and adaptability to climate change. This analytical strategy is consistent with vulnerability assessment and *shift-in-risk* perspectives. For systems such as agriculture, forestry, water resources, and coastal zone settlements, the key climatic stimuli are not average conditions but variability and extremes.

A direct climatic condition prompts adaptation less often than the economic and social effects or implications of the climatic stimuli that are fundamental in triggering adaptive responses. Non-climatic conditions are important in moderating and sometimes overwhelming the influence of climate stimuli in the decision making of resource users. Decisions on adaptation are rarely made in response to climate stimuli alone. These findings are important for predicting autonomous adaptations and for improving adaptation assumptions in impact models.

In estimating future adaptations and developing adaptation policies, it is helpful to understand factors and circumstances that hinder or promote adaptation. As Rayner and Malone (1998) conclude, the consequences of a climate event are not direct functions of its physical characteristics; they also are functions of the ways in which a society has organized its relation to its resource base, its relations with other societies, and the relations among its members. Numerical impact assessment models tend to *use*, rather than *generate*, information on adaptations to estimate future impacts of climate stimuli, after the effects of adaptation have been factored in. They indicate the potential of human systems to adapt autonomously and thus to moderate climate change damages.

3.7. Costs of Adaptation

As assessments of climate impacts (commonly measured as *costs* that include damages and benefits) increasingly have incorporated expected adaptations, and particularly as impact models and *integrated assessment* models have shown the potential of adaptation to offset initial impact costs, interest has grown in calculating the costs of autonomous adaptations. Whether climate change or another climate stimulus is expected to have problematic or "dangerous" impacts depends on the adaptations and their costs. Climate change impact cost studies that assume adaptation also should include the "adjustment of costs" of these adaptations. Tol (1995, 1999) provide comprehensive summary of analyses of the costs of autonomous, mainly reactive adaptations, undertaken privately (i.e., not adaptation policies of government). A common basis for evaluating impact costs is to sum adaptation costs and residual damage costs.

Procedures for defining and calculating such adaptation costs are subject to ongoing debate. Tol (1995, 1999) note adaptation costs but ignore transition costs. Most research to date on adaptation *costs* is limited to particular economic measures of well-being. Any comprehensive assessments of adaptation costs are consider not only economic criteria but also social welfare and equity. Cost estimation for autonomous adaptations is not only important for impact assessment; it also is a necessary ingredient in the *base case, reference scenario*, for evaluations of policy initiatives, with respect to both adaptation and mitigation (Smit *et al.*, 2000).

3.7.1. Adaptation Experiences and Learning

Climate change will be experienced via conditions that vary from year to year, as well as for ecosystems and human systems; these variations are important for adaptation. Research in many sectors and regions indicates an impressive human adaptive capacity to long-term average climate conditions but less success in adapting to extremes and to year-to-year variations in climatic conditions. Although human settlements or agricultural systems have adapted to be viable in a huge variety of climatic zones around the world, those settlements and systems often are vulnerable to temporal deviations from normal conditions. As a result, adaptations designed to address changed mean conditions may or may not be helpful in coping with the variability that is inherent in climate change.

All socioeconomic systems, especially climate-dependent systems such as agriculture, forestry, water resources, and human health, are continually in a state of flux in response to changing circumstances, including climatic conditions. The evidence shows that there is considerable potential for adaptation to reduce the impacts of climate change and to realize new opportunities. Adaptation options occur generally in socioeconomic sectors and systems in which the turnover of capital investment and operating costs is shorter and less often where long-term investment is required.

Although an impressive variety of adaptation initiatives have been undertaken across sectors and regions, the responses are not universally or equally available. Viability of crop insurance depends heavily on the degree of information, organization, and subsidy available to support it. Similarly, the option of changing location in the face of hazard depends on the resources and mobility of the affected part and on the availability and conditions in potential destination areas.

Adoption of adaptive measures is constrained by other priorities, limited resources, or economic or institutional barriers. There is some evidence that the costs of adaptations to climate conditions are growing. There is strong evidence of a sharp increase in damage costs of extreme climatic or weather events. Growing adaptation costs reflect, at least in part, increases in populations and/or improvements in standards of living, with more disposable income being used to improve levels of comfort, health, and safety in the short run. Many adaptations to reduce vulnerability to climate change risks also reduce vulnerability to current climate variability, extremes, and hazards (Rayner and Malone, 1998). Adaptation strategies in agriculture should be clear applications to climate change, including moisture-conserving practices, hybrid selection, and crop substitution. In the water resources sector, Current management practices might represent useful adaptive strategies for climate change. Societal responses to large environmental challenges tend to be incremental and ad hoc rather than fundamental (Rayner and

Malone, 1998). There is little evidence that efficient and effective adaptations to climate change risks will be undertaken autonomously.

A consistent lesson from adaptation research is that climate is not the singular driving force of human affairs that is sometimes assumed—but neither is it a trivial factor. Climate is an important resource for human activities and an important hazard. Climate change is a source of significant stresses or opportunities for societies, yet it has always been only one factor among many. The consequences of a shift in climate are not calculable from the physical dimensions of the shift alone; they require attention to human dimensions through which they are experienced.

Some studies show faith in market mechanisms and suggest considerable capacity of human systems to adapt autonomously. Other studies highlight the constraints on *optimal* autonomous adaptation, such as limited information and access to resources, adaptation costs, and residual damages; these studies emphasize the need for planned, especially anticipatory, adaptations undertaken or facilitated by public agencies.

4. ADAPTIVE CAPACITY

Adaptive capacity is the potential ability of a system, and the region or community adapts to the effects or impacts of climate change. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extremes. Enhancement of adaptive capacity reduces vulnerabilities. Thus, it promotes sustainable development (Munasinghe, 2002; Smit *et al.*, 2000). Considerable attention has been given to the characteristics of communities, countries, and regions that influence their propensity or marginal additional ability to adapt. Hence, their vulnerability to risks is highly associated with climate change.

Considerable attention has been devoted to the characteristics of systems that influence their propensity or ability to adapt and/or their priority for adaptation measures. These characteristics have been called *determinants of adaptation*. Generic concepts such as sensitivity, vulnerability, susceptibility, coping range, critical levels, adaptive capacity, stability, robustness, resilience, and flexibility have been used to differentiate systems according to their likelihood, need, or ability for adaptation (Kelly and Adger, 1999). These characteristics influence the occurrence and nature of adaptations and thereby circumscribe the vulnerability of systems and their residual impacts. In the hazards literature, these characteristics are reflected in socially constructed or endogenous risks. Together represents the adaptive capacity of a system.

4.1. Adaptive Capacity and Vulnerability

Adaptive capacity refers to the potential, capability, or ability of a system to adapt to climate change impacts. Adaptive capacity greatly influences the vulnerability of communities and regions to climate change effects and hazards (Kelly and Adger, 1999). Human activities and groups are considered sensitive to climate to the degree that they can be affected by it and vulnerable to the degree. Because vulnerability and its causes play essential roles in determining impacts, understanding the dynamics of vulnerability is as important as understanding climate itself.

The significance of climate variation or change depends on the change itself and the characteristics of the society exposed to it (Munasinghe, 2002). These characteristics of society determine its adaptive capacity and its adaptability. Adaptive capacity refers to the ability to prepare for hazards and opportunities in advance and to respond or cope with the effects. Studies of similar hazardous events recurring at different times in a given region show vastly different consequences because of societal transformations that occurred between the events. As per observation of researchers, rainfall and temperature fluctuations in Western Europe have far milder effects on human well-being today, in other words, society generally is less vulnerable than they did in the medieval and early modern periods, essentially as a result of enhanced adaptive capacity that reflects changes in practices, economics, and government programs. Similarly, particular climate events or hazards can have *vastly different consequences for those on whom they infringe because of differences in coping ability* (Rayner and Malone, 1998). An extreme climatic event will result in higher losses of life in a developing country than in a developed country because of differential adaptive capacity. It should be noted that in most poor developing countries, socioeconomic, technical, and political barriers will mean that the changed health risks will not be addressed.

Research on comparative adaptive capacity and vulnerability is evolving, and its difficulties are well recognized. Estimates of adaptive capacity tend to be based on premises such as the position that highly managed systems, given sufficient resources, are likely to be more adaptable (and at a lower cost) than less managed ecosystems (Toman 2006). It is also widely accepted that systems with high levels of capacity to cope with high adaptive capacity for stresses associated with climatic change.

4.2. Determinants of Adaptive Capacity

The *determinants of adaptive capacity* relate to the economic, social, institutional, and technological conditions that facilitate or constrain the development and deployment of adaptive measures (Rayner and Malone, 1998; Kelly and Adger, 1999) and we discuss these in detail later. As per IPCC adaptation is the adjustment in ecology, socio-economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities. Adaptation involves (i) building adaptive capacity that increases the ability of individuals, groups, and organisations to adapt to changes, and (ii) implementing adaptation decisions that transform the capacity into action. Both dimensions of adaptation are required to prepare for or in response to impacts generated through changing climate.

Adaptation to climate change and related risks takes place in a dynamic social, economic, technological, biophysical, and political context that varies over time. This complex mix of conditions determines the capacity of systems to adapt. Although scholarship on adaptive capacity is extremely limited in the climate change field, there is considerable understanding of the conditions that influence the adaptability of societies to climate change in the fields of resource management, and sustainable development. From this literature, it is possible to identify the main features of communities or regions that seem to determine their adaptive capacity: economic resources, technology, information, knowledge and skills, infrastructure, institutions etc.

4.2.1. Resources

Resources can be expressed as the economic assets, capital resources, financial means, wealth, or poverty, the economic condition of nations and groups. Clearly resource is a determinant of adaptive capacity (Brooks *et al.*, 2005). It is true that developed nations are better prepared to bear the costs of adaptation to climate change impacts and risks than poorer nations. Poverty is directly related to vulnerability and it is a rough indicator of the ability to cope. The poor are among the most vulnerable to famine, malnutrition, and hunger. There is a situation in India in which pastoralist communities are *locked into* a vulnerable situation in part because of a lack of financial power that would allow them to diversify and engage in other sources of income. At a local level, the highest levels of household vulnerability in coastal area may be characterized by low household incomes in conjunction with poor housing quality and little community organization. Community with higher levels of household income are better able to manage vulnerability through the transfer of flood impacts from health to economic investment and loss. Kelly and Adger (1999) demonstrate the influence of poverty on a region's coping capacity; poor regions tend to have less diverse and more restricted entitlements and a lack of empowerment to adapt. There is ample evidence that poorer nations and disadvantaged groups within nations are especially vulnerable to disasters.

4.2.2. Technology

Lack of technology has the potential to seriously impede a nation's ability to implement adaptation options by limiting the range of possible responses. Adaptive capacity is likely to vary, depending on availability and access to technology at various levels (i.e., from local to national) and in all sectors. Many of the adaptive strategies identified as possible in the management of climate change directly or indirectly involve technology (e.g., warning systems, protective structures, crop breeding and irrigation, settlement and relocation or redesign, flood control measures).

Hence, a community's current level of technology and its ability to develop technologies are important determinants of adaptive capacity. Moreover, openness to the development and utilization of new technologies for sustainable extraction, use, and development of natural resources is key to strengthening adaptive capacity. For example, in the context of Asian agriculture and the impact of future climate change, the development of heat-resistant rice cultivators will be especially crucial. Regions with the ability to develop technology have enhanced adaptive capacity.

4.2.3. Knowledge

Successful adaptation depends on knowledge, information and skill. Success of adaptation requires recognition of the necessity to adapt, knowledge about available options, the capacity to assess them, and the ability to implement the most suitable ones. As information on weather hazards becomes more available and understood, it is possible to study, discuss, and implement adaptation measures. Building adaptive capacity requires a strong, unifying vision; scientific understanding of the problems; an openness to face challenges; pragmatism in developing solutions; community involvement; and commitment at the highest political level. Lack of trained and skilled personnel can limit a nation's ability to implement adaptation options. In general, countries with higher levels of stores of human knowledge are considered to have greater adaptive capacity than developing nations and those in transition.

Illiteracy along with poverty is a key determinant of low adaptive capacity in under developed countries. It is important to ensure the systems that are in place for the dissemination of climate change and adaptation information nationally and regionally and that there are forums for discussion and innovation of adaptation strategies at various levels.

4.2.4. Infrastructure

Adaptive capacity is likely to vary with social infrastructure. Some researchers regard the adaptive capacity of a system as a function of *availability of* and *access to* resources by decision makers, as well as vulnerable subsectors of a population (Kelly and Adger, 1999). In the coastal area of Hong Kong, the capacity to adapt to the risk of typhoons differs for existing urban areas and for new coastal land reclamation. For existing urban areas, there is no possibility of retreat or accommodation, although during urban renewal the formation level of the ground could be raised, thereby decreasing the vulnerability of settlements. At the community level, the lack of flexibility in formal housing areas where dwelling form and drainage infrastructure were more fixed reduced the capacity to respond to contemporary environmental conditions.

4.2.5. Institutions

In general, countries with well-developed social institutions are considered to have greater adaptive capacity than those with less effective institutional arrangements—commonly, developing nations and those in transition. The role of inadequate institutional support is frequently cited in the literature as a hindrance to adaptation. Kelly and Adger (1999) show how institutional constraints limit entitlements and access to resources for communities in coastal Vietnam and thereby increase vulnerability. Inherent institutional deficiencies and weaknesses in managerial capacities are difficult to cope with the anticipated natural event. It would be extremely difficult for the country to reduce vulnerability to climate change. Unstable agricultural policies increased the vulnerability of the food production sector in Less developed countries (LDC). Drastic changes in economic and policy conditions are expected to make agricultural systems more vulnerable to changes in climate. Some time, resilient to climate change is the need to change tenure conditions and other arrangements may create conflicts that are beyond the capacity of local institutions to resolve. In the water resource sector, present day strategies, demand management tools, and measures (i.e., institutions) have evolved over time and are capable of serving as a basis for adaptive response strategies to climate change.

4.2.6 Accessibility

Adaptive capacity of a society depends on resource and information availability, and these should be easily accessible and equal justice to all. Truly, the determinants of adaptive capacity are not independent of each other, nor are they mutually exclusive. Adaptive capacity is the outcome of a combination of determinants and varies widely between countries and groups, as well as over time. Not only are conditions for adaptive capacity diverse, they also behave differently in different countries and regions, particularly depending on the level of development. These determinants represent conditions that constrain or enhance the adaptive capacity and hence the vulnerability of regions, nations, and communities.

4.3. Enhancing Adaptive Capacity

The adaptive capacity of a system or nation is likely to be greater when the following requirements are met:

1. The nation has a stable and prosperous economy. Regardless of biophysical vulnerability to the impacts of climate change, developed and wealthy nations are better prepared to bear the costs of adaptation than developing countries.
2. There is a high degree of access to technology at various levels (i.e., from local to national) and in all sectors. Moreover, openness to development and utilization of new technologies for sustainable extraction, use, and development of natural resources is key to strengthening adaptive capacity.
3. The roles and responsibilities for implementation of adaptation strategies are well delineated by central governments and are clearly understood at national, regional, and local levels.

4. Systems are in place for the dissemination of climate change and adaptation information, nationally and regionally, and there are forums for the discussion and innovation of adaptation strategies at various levels.
5. Social institutions and arrangements governing the allocation of power and access to resources within a nation, region, or community assure that access to resources is equitably distributed because the presence of power differentials can contribute to reduced adaptive capacity.
6. Existing systems with high adaptive capacity are not compromised. For example, in the case of traditional or indigenous societies, pursuit of western/European-style development trajectories may reduce adaptive capacity by introducing greater technology dependence and higher density settlement and by devaluing traditional ecological knowledge and cultural values.

4.4. Scale of Adaptive Capacity

There is considerable variation among countries with regard to their capacity to adapt to climate change. Given their economic affluence and stability; their institutions and infrastructures; and their access to capital, information, and technology, developed nations are broadly considered to have greater capacity to adapt than developing regions or countries in economic transition. In general, countries with well-developed social institutions supported by higher levels of capital and stores of human knowledge are considered to have greater adaptive capacity (Smith and Lenhart, 1996). Adaptation options—including traditional coping strategies—often are available in developing countries and countries in transition; in practice, however, those countries' capacity to effect timely response actions may be beyond their infrastructure and economic means (IPCC, 1997). For those countries, the main barriers are: i) asymmetry in financial/market that leads to uncertain pricing, availability of capital, lack of credit ii) weak institutional structure, institutional instability iii) Social/cultural rigidity in land-use practices, social conflicts iv) technological existence, access v) lack of information, trained personnel.

It should be noted that a considerable disparity between developed and developing countries in terms of potential adverse effects of climate change on agricultural systems; and developing countries suffer the greatest losses. In addition, poorer, developing regions presumably will face stricter constraints on technology and institutions and those measures taken in response to climate change may be very demanding financially. Researchers also believe that compared to industrialized countries, developing countries possess a lower adaptive capacity as a result of greater reliance on climatic resources.

Various studies have attempted to identify overall trends that cause increased or decreased vulnerability to environmental hazards; unfortunately, however, the concept of vulnerability does not rest well on a developed theory. Empirical local-level studies of vulnerability are so complex, however, that attempts to describe patterns or estimate trends at global or regional scales are extremely difficult. Social change has the potential to make individuals or activities more vulnerable in some ways and less vulnerable in others (Rayner and Malone, 1998). The influence of changes in the determinants of adaptive capacity are not necessarily direct or clear, rendering the attempt to develop systematic indices for measurement and comparison a difficult task.

4.4.1. Capacity Enhancement by Scale

The vulnerabilities and anticipated impacts of climate change will be observed at different scales and levels of society—and enhancement of adaptive capacity can be initiated at different social scales. Truly, there are four scales –namely: mega, macro, meso, and micro. Using the example of sea-level rise as a climate change impact, the authors describe adaptation options at each scale. The process of sea-level rise occurs at the mega-scale and is global in its effect. At the macro-scale, an associated increase in surface water and groundwater has the potential to similarly affect neighbouring rivers and flood plains in China, Nepal, India, Bhutan, and Pakistan. Adaptive capacity at this scale is a function of international economic and political structures, with implications for the country's capital and technological resources and institutions. At the meso-scale, different communities within Bangladesh are differentially vulnerable, depending on adaptive capacity and physiographic characteristics. At this scale, location-specific adaptation options would need to be considered. Finally, at a micro-scale, family units and individuals would experience vulnerabilities irrespective of the origin of the processes and would employ adaptations within their particular economic and socio-cultural constraints. Vulnerabilities of climate change occur at various scales, successful adaptation will depend on actions taken at a number of levels. Examples of initiatives to enhance adaptive capacity at various scales follow:

4.4.1.1 Global Level

Greater cooperation between industrialized and developing countries to align global and local priorities by improving policy/science interactions and working toward greater public awareness of climate change and adaptation issues; inclusion of global institutions for global-level adaptation, which would include research and facilitation of policy, funding, and monitoring at all levels; removal of barriers to international trade. It is argued that improving market conditions, reducing the exploitation of marginal land, accelerating the transfer of technology, and contributing to overall economic growth will promote both sustainability and adaptive capacity; effective global economic participation. Benefits go beyond direct financial gain and include technology transfers, technical and managerial skills transfers, and other skills transfers associated with the learning by doing process.

4.4.1.2 National Level

Development of climate change policy that is specifically geared toward more vulnerable sectors in the country (Mustafa, 1998), with an emphasis on poverty reduction (Kelly and Adger, 1999); Establishment of broadly based monitoring and communication systems or establishment of public policy that encourages and supports adaptation at local or community levels and in the private sector; Pursuit of sustainable economic growth, which, in turn, allows for greater dedication of resources to development of adaptive technologies and innovations.

4.4.1.3 Local Level

Establishment of social institutions and arrangements that discourage concentration of power in a few hands and prevent marginalization of sections of the local population; arrangements need to consider representativeness of decision making bodies and maintenance of flexibility in the functioning of local institutions; Encouragement of diversification of income sources (and therefore risk-spreading), particularly for poorer sectors of society (Adger and Kelly, 1999); Encouragement of formal or informal arrangements for collective security (Kelly and Adger, 1999); Identification and prioritization of local adaptation measures and provision of feedback to higher levels of government. These efforts would have to be reinforced by the adequate provision of knowledge, technology, policy, and financial support.

4.4.2 Successful Adaptation

Adaptation to climate change impacts is observed in both physical and ecological systems as well as in human adjustments to resource availability and risk at different spatial and societal scales. Adger et al. (2005) outline a set of normative evaluative criteria for the success of adaptations at different scales. They argue that elements of effectiveness, efficiency, equity and legitimacy are important in judging success in terms of sustainability of development path.

5. SUSTAINABLE DEVELOPMENT

Sustainable development refers to maintaining development over time. Adaptive capacity to deal with climate risks is closely related to sustainable development. Enhancement of adaptive capacity is fundamental to sustainable development. Several researchers study by assessing differences in vulnerability among regions and groups and by working to improve the adaptive capacity of those regions and groups, planned adaptation can contribute to equity considerations of sustainable development.

In the context of African agriculture, Downing *et al.* (1996) conclude that enhancement of present resource management activities is necessary to prepare for potential impacts of climate change. In Malawi, economic progress ensures food production and reduces vulnerability to climate risks that is consistent with Malawi's planning and development initiatives. Because vulnerability to climate depends on the adaptive capacity of a wide range of attributes, it may be unrealistic to focus on development programs that deal with adaptation to climate alone (Rayner and Malone, 1998).

Ability to adapt clearly depends on the state of development or developmental position. Underdevelopment basically constrains adaptive capacity. The reason is lack of resources to hedge against extreme or expected events. The process of enhancing adaptive capacity is not simple; it involves spurts of growth inter-dispersed with periods of consolidation, refocusing and redirection.

5.1. Adaptive Capacity for Sustainable Development

Enhancement of adaptive capacity involves similar requirements as promotion of sustainable development, including (i) Improved access to resources; (ii) Reduction of poverty; (iii) Lowering of inequities in resources and wealth among groups; (iv) Improved education and information; (v) Improved infrastructure; (vi) Diminished intergenerational inequities; (vii) Respect for accumulated local experience; (viii) Moderate long-standing structural inequities; (ix) Assurance that responses are comprehensive and integrative, not just technical; (x) Active participation by concerned parties, especially to ensure that actions match local needs and resources; (xi) Improved institutional capacity and efficiency. Actions taken without reference to climate have the potential to affect vulnerability to it, enhancement of adaptive capacity to climate change can be regarded as one component of broader sustainable development initiatives (Munasinghe, 2002). Hazards associated with climate change have the potential to undermine progress with sustainable development. So, it is important for sustainable development initiatives to explicitly consider hazards and risks associated with climate change.

Yet there is surprisingly little recognition of climate hazards and risks associated with climate change in established development projects and programs. O'Brian et al. (2004) show how climate change can have serious implications for development projects planned or underway in Mexico, including hydroelectric and irrigation initiatives. Torvanger (1998) shows how climate flexibility considerations that can be built into development investments at modest incremental costs are applicable regardless of the uncertainties of climate change.

6. FUTURE ADAPTATIONS

The degree to which a future climate change risk is dangerous depends greatly on the likelihood and effectiveness of adaptations in the system. An improved process of adaptation or/and better information on the conditions under which adaptations of various types are expected to occur. Adaptation is necessary to make informed judgments on the vulnerabilities of sectors, regions, and communities. Insights into processes of adaptation have been gained from several types of analysis, including listing of possible adaptation measures, impact assessment models, adaptation process models, historical and spatial anagoges, and empirical analysis of contemporary adaptation processes.

6.1. Possible Adaptation Measures

There are many arbitrary lists of possible adaptation measures, initiatives, or strategies that have a potential to moderate impacts, if they were implemented. Such *possible* adaptations are based on experience, observation, and speculation about alternatives that might be created; they cover a wide range of types and take numerous forms (UNEP, 1998).

Similarly, in coastal zone studies, comprehensive lists of potential adaptation measures are presented; these adaptations include a wide array of engineering measures, improvements, or changes, including agricultural practices that are more flood-resistant; negotiating regional water-sharing agreements; providing efficient mechanisms for disaster management; developing desalination techniques; planting mangrove belts to provide flood protection; planting salt-tolerant varieties of vegetation; improving drainage facilities; establishing setback policies for new developments; developing food insurance schemes; devising flood early warning systems; and so forth. They show that there is a large variety and number of possible adaptations, including many with the potential to reduce adverse climatic change impacts.

Many of these adaptations—especially in agriculture, water resources, and coastal zone applications—essentially represent improved resource management, and many would have benefits in dealing with current climatic hazards as well as with future climatic risks.

6.2. Planned Adaptations and Evaluation of Policy Options

This section considers *planned*, mainly *anticipatory* adaptations, undertaken or directly influenced by *governments* or collectives as a public policy initiative. These adaptations represent conscious policy options or response strategies to concerns about climate change. Public adaptation initiatives may be direct or indirect, such as when they encourage or facilitate private actions.

6.2.1. Objectives for Planned Adaptations

Several reasons have been given for pursuing planned adaptations. Public adaptation initiatives are necessary strategy to manage the impacts of climate change. Adaptation can yield benefits regardless of the uncertainty and nature of climate change. Public adaptation policies rely on private actions. Public agencies should undertake planned adaptation strategies, particularly following relationships with other policy and management objectives, and the evaluation criteria. There are five major objectives of adaptation: a) Enhancing the adaptability of vulnerable natural systems, b) Reversing trends that increase vulnerability. It is also termed as *mal-adaptation*. c) Improving societal awareness and preparedness, d) Increasing robustness of infrastructural designs and long-term investments, e) Increasing the flexibility of vulnerable managed systems.

6.2.2. Identification of Adaptation Policy Options

Research addressing future adaptations to climate change tends to be normative, suggesting anticipatory adaptive strategies to be implemented through public policy. Generally, such adaptation recommendations are based on forecasts of expected climate change. Recommended adaptations tend to be in response to changes in *long-term mean climate*, though more specific elements of climate change (e.g., sea-level change) gain focus when sector specific adaptations are proposed (e.g., integrated coastal zone management) (Smith *et al*., 2000), and some studies specifically examine potential adaptations to variability and extreme events.

Range in scope from very broad strategies for adaptation (enhancing decision makers' awareness of climatic change and variability) to recommendations of sector specific policy. Sectors receiving particular attention include water resources, coastal resources, agriculture, and forest resources.

Tend to be *regionally focused*, in recognition of the fact that vulnerability to the impacts of climate change is highly spatially variable. There is interest in developing countries and nations with economies in transition, given their greater reliance on natural systems-based economic activity (like agriculture) (Smith *et al*., 2000; Kelly and Adger, 1999). Because no single set of adaptive policy recommendations can be universally appropriate, several studies suggest means by which proposed adaptations may be selected and evaluated. At a very basic level, the success of potential adaptations is seen to depend on the *flexibility* or effectiveness of the measures, such as their ability to meet stated objectives given a range of future climate scenarios, and their potential to produce *benefits that outweigh costs*. Clearly, these are difficult criteria to assess, given the complexity of adaptation measures, the variable sensitivities and capacities of regions, and uncertainties associated with climate change and variability. Some research (Smith *et al.*, 2000) offers supplementary characteristics of, or criteria for, the identification of adaptations:

The measure generates benefits to the economy, environment, or society under current conditions. The measure addresses high-priority adaptation issues such as irreversible or catastrophic impacts of climate change, long-term planning for adaptation, and unfavourable trends. The measure targets current areas of opportunity. The measure is feasible—that is, its adoption is not significantly constrained by institutional, social/cultural, financial, or technological barriers. The measure is consistent with, or even complementary to, adaptation or mitigation efforts in other sectors.

6.2.3. Evaluation of Adaptation Options and Adaptation Costs

There are some important steps should be identify and evaluate planned adaptations, and anticipatory adaptation policies in the climate change context. This approach should covered management of institutional processes and players and proposes net benefits and implementability as central evaluative criteria. Numerous other considerations are noted, including flexibility, benefits independent of climate change, local priorities, levels of risk, and time frames of decisions.

From a disaster management perspective, Tol (1995, 1999) argue that policies must be evaluated with respect to economic viability, environmental sustainability, public acceptability, and behavioural flexibility. Tol (1995, 1999) apply these observations in an examination of adaptation to increased risk of river floods in the Netherlands. They note several possible adaptations, but none could be accomplished without creating significant distributional and/or ecological impacts. None, therefore, would be feasible without enormous political will and institutional reform. There should be multi-criteria methodologies for evaluation, including cost-benefit, cost-effectiveness, risk-benefit to evaluate possible adaptation options have been demonstrated for coastal zones and agriculture.

In an economic efficiency framework, adaptation actions are justified as long as the additional costs of adaptation are lower than the additional benefits from the associated reduced damages. Optimal levels of adaptation are based on minimizing the sum of adaptation costs and residual damage costs. Such studies require the definition of a base case that involves estimation of autonomous adaptations. These and other normative studies illustrate the range of principles and methods that have been proposed for identifying, evaluating, and recommending adaptation measures. Adaptation is a continuous and iterative cycle, involving several steps: information collection and awareness raising, planning and design, implementation, monitoring, and evaluation.

6.2.4. Public Adaptation Decisions, Uncertainty, and Risk Management

Research increasingly addresses how adaptation is considered in actual policy decision making. Institutions and planning processes can deal with climate change; such processes essentially represent adaptive management. As in many other sectors and circumstances, adaptation to climate change hazards in the coastal zone is part of ongoing coastal zone management. Adaptation to sea-level rise and extreme climate events is being included in Japanese coastal policies, British shoreline management, and Dutch law and coastal zone management.

Planning of adaptation invariably is complicated by multiple policy criteria and interests that may be in conflict. For example, the economically most efficient path to implement an adaptation option might not be the most effective or equitable one. Moreover, decisions have to be made in the face of uncertainty, which is pertinent to adaptation that are associated with climate change itself, its associated extremes, their effects, the vulnerability of systems and regions, conditions that influence vulnerability, and many attributes of adaptations, including their costs, implement ability, consequences, and effectiveness. Adaptation strategies are described as forms of risk management. For example, adaptations to deal with climate change impacts or risks to human health can be biological (acquired immunity), individual (risk-aversion options), or social. Most social adaptation strategies are measures to reduce health risks via public health programs. Similarly, public adaptations via *disaster loss mitigation* are mainly risk management initiatives such as improved warning and preparedness systems, less vulnerable buildings and infrastructure, risk-averse land use planning, and more resilient water supply systems.

To recognize uncertainties, decision tools to help evaluate adaptation options include risk-benefit and multi-criteria analyses. Such evaluations are further complicated by the existence of secondary impacts related to the adaptation itself. For example, water development projects (adaptations to water supply risks) can have significant effects on local transmission of parasitic diseases, including malaria. Improved water supply in some rural areas of Asia has resulted in a dramatic increase in Aedes mosquito breeding sites and, consequently, outbreaks of dengu. Existing resource management programs do not necessarily consider changed risks or recognize local interests and inequities. The reactive crisis management is ineffective and hence, the need is for proactive and cooperative planning. Nonetheless, it is widely accepted that planned adaptations to climate risks are most likely to be implemented when they are developed as components of existing resource management programs or as part of national or regional strategies for sustainable development (Munasinghe, 2002).

6.2.5. Limitations of Adaptation

There is a recognised need to adapt to changing climatic conditions. At the same time there is an emerging discourse of limits to such adaptation. Limits are immutable thresholds in biological, economic or technological parameters. Limits to adaptation are endogenous to society and hence contingent on ethics, knowledge, attitudes to risk and culture. Adger et al. (2009) review insights from history, sociology and psychology of risk, economics and political science to develop four propositions concerning limits to adaptation: (i) any limits to adaptation depend on the ultimate goals of adaptation underpinned by diverse values, (ii) adaptation need not be limited by uncertainty around future foresight of risk, (iii) social and individual factors limit adaptation action, and (iv) systematic undervaluation of loss of places and culture disguises real, experienced but subjective limits to adaptation. Truly, these issues of values and ethics, risk, knowledge and culture construct societal limits to adaptation, but that these limits are mutable.

Successful adaptation to climate change is bounded by limiting factors. Societal adaptation is not necessarily limited by exogenous forces outside its control. Adaptation to climate change is limited by the values, perceptions, processes and power structures within society. What may be a limit in one society may not be in another, depending on the ethical standpoint, the emphasis placed on scientific projections, the risk perceptions of the society, and the extent to which places and cultures are valued. The role of *ethics* and its manifestation in the diverse goals of adaptation of different actors is critical. One failure of adaptation may in fact be a successful adaptation for another actor, resulting from the different priorities and values held within society. Lack of precise *knowledge* about future climate impacts is often cited as a reason for delaying adaptation actions. It becomes a limit in itself, even where greater foresight will not facilitate adaptation. Adaptation decisions depend on the perceptions of *risk* held by society, which may act as limiting factors if the society does not believe the risk is great enough to justify action. The undervaluing of *places and cultures* may limit the range of adaptation actions. The current methods of valuing loss do not include cultural and symbolic values, leading to an undervaluation in comparison with more easily valued and tangible assets.

The major implication arises from literature that diverse and contested values —underpinned by ethical, cultural, risk and knowledge considerations — underlie adaptation responses and subjective limits to adaptation. Given diverse values of diverse actors, there is a compelling need to identify and recognise implicit and hidden values and interests in advance of purposeful adaptation interventions. As a consequence, there is a requirement for governance mechanisms that can meaningfully acknowledge and negotiate the complexity arising from the manifestation of diverse values for adaptive action involving wide sets of stakeholders. It is true that locality, place and cultural values are likely to loom large in adaptation decisions.

Climate change adaptation is not only limited by exogenous forces, but importantly by societal factors that could possibly be overcome. An adaptable society is characterized by awareness of diverse values, appreciation and understanding of specific and variable vulnerabilities to impacts, and acceptance of some loss through change. The ability to adapt is determined in part by the availability of technology and the capacity for learning but fundamentally by the ethics of the treatment of vulnerable people and places within societal decision-making structures.

7. CONCLUSION

Adaptation is an important part of societal response to global climate change. This chapter provides clear concept of adaptation to climate change, different types of adaptation, measurement and adaptation capacity. Planned or anticipatory adaptation has the potential to reduce vulnerability and realize opportunities associated with climate change effects and hazards. There are numerous examples of successful adaptations that would apply to climate change risks and opportunities. Substantial reductions in climate change damages can be achieved, especially in the most vulnerable regions, through timely deployment of adaptation measures.

In the absence of planned adaptation, communities will adapt autonomously to changing climatic conditions, but not without costs and residual damages. Societies and economies have been making adaptations to climate for centuries. However, losses from climate-related extreme events are substantial and, in some sectors, increasing—indicating patterns of development that remain vulnerable to temporal variations in climatic conditions.

Most communities, sectors, and regions are reasonably adaptable to changes in average conditions, unless those changes are particularly sudden or not smooth. However, these communities are more vulnerable and less adaptable to changes in the frequency and/or magnitude of conditions other than average, especially extremes. Changes in the frequency and magnitude of extremes underlie changes in mean conditions and thus are inherent in climate change; adaptation initiatives to these hazards are of particular need. Adaptations to current climate and climate-related risks (recurring droughts, storms, floods, and other extremes) generally are consistent with adaptation to changing and changed climatic conditions. Adaptations to changing climatic conditions are more likely to be implemented if they are consistent with or integrated with decisions or programs that address non-climatic stresses.

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KEY TERMS AND DEFINITIONS

Adaptation: Adaptation is the adjustment with changing conditions. It is a change of traditional practices for non-declining welfare due to effects of climate change. Adaptation refers to changes in practices, processes, or restructures to minimise or offset potential damages associated with changes in climate. Adaptation involves adjustments to reduce the vulnerability of communities, or regions, or nations.

Adaptive Capacity: Adaptive capacity is the potential ability of a system, and the region or community adapts to the effects or impacts of climate change. Enhancement of adaptive capacity represents a practical means of coping with changes and uncertainties in climate, including variability and extremes. Enhancement of adaptive capacity reduces vulnerabilities.

Climate Change: Climate change is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time. Climate change refers to a change in average weather conditions, or in the time variation of weather around longer-term average conditions.

Risk: Risk is the potential of losing something of value. Values can be gained or lost when taking risk resulting from a given action, activity and/or inaction, foreseen or unforeseen. Risk can also be defined as the intentional interaction with uncertainty, which is a potential, unpredictable, immeasurable and uncontrollable outcome. Risk is a consequence of action taken in spite of uncertainty.

Sustainable Development: According to Brundtland report (1987), Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: (i) the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and (ii) the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. Sustainable development is a process for achieving sustainability in any activity that uses resources and where immediate and intergenerational replication is demanded. Sustainable development is the organizing principle for sustaining finite resources necessary to provide for the needs of future generations of life on the planet.

Vulnerability: Vulnerability, in this context, may be defined as the diminished capacity of an individual or group to anticipate, cope with, resist and recover from the impact of a natural or man-made hazard. The concept is relative and dynamic. Vulnerability is most often associated with poverty, but it can also arise when people are isolated, insecure and defenceless in the face of risk, shock or stress. People differ in their exposure to risk as a result of their social group, gender, ethnic or other identity, age and other factors.

Section 8
Agriculture

Chapter 19
Climate Change and Agriculture:
Impacts, Adoption, and Mitigation

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ABSTRACT

Increasing evidence shows that shifts in Earth's climate have already occurred and indicates that changes will continue in the coming years. This chapter is an attempt to distil what is known about the likely effects of climate change on food security and nutrition in coming decades. Apart from few exceptions, the likely impacts of climate change on agricultural sector in the future are not understood in any great depth. There are many uncertainties as to how changes in temperature, rainfall and atmospheric carbon dioxide concentrations will interact in relation to agricultural productivity. The consequences of climate change on various important aspects of agriculture such as crop production, livestock, availability of water, pest and diseases etc. are discussed and summarized. Each of this aspect of agriculture sector will have certain impact which may be positive or negative. The chapter also discusses on the possible mitigation measures and adaptations for agriculture production in the future climate change scenarios.

INTRODUCTION

Climate is a measure of the average pattern of variation in climatic parameters like precipitation, temperature, humidity, wind, atmospheric pressure, atmospheric particle count and other meteorological variables in a given region over long periods of time. These climatic parameters are changing due to global warming. So the climate change has long-since ceased to be a scientific curiosity and is no longer just one of many environmental and regulatory concerns (UNEP, 2015). In addition, the CO_2 concentrations and other greenhouse gases such as methane, nitrous oxides, chlorofluorocarbons and chlorofluorocarbon substitutes will continue to rise (Hartwell et al. 1996). The American Meteorological Society (AMS, 2015) explained climate change may be due to natural external forcing, such as changes in solar emission or slow changes in the earth's orbital elements; natural internal processes of the climate system; or anthropogenic forcing.

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The world's climate is changing, and the changes will have an enormous impact on people, ecosystems, and energy use. According to the latest report of the Intergovernmental Panel on Climate Change (IPCC), average global temperature is likely to rise by another 2 to 8.6 degrees F by 2100. Further UNEP (2015) reported that there is alarming evidence that important tipping points, leading to irreversible changes in major ecosystems and the planetary climate system, may already have been reached or passed. It is a growing crisis with economic, health and safety, food production, security, and other dimensions. The shifting weather pattern has threatened food production and food security on the globe. At the end of this century, different locations will experience different levels of increases in temperature, with the greatest impact toward the North Pole and the least increase toward the South Pole and in the tropics.

Climate is the long-term statistical expression of short-term weather. Climate can be defined as "expected weather". When changes in the expected weather occur, we call these climate changes. American Meteorological Society defines climate and climate change as follows (AMS, 2015).

- **Climate:** The slowly varying aspects of the atmosphere–hydrosphere–land surface system.

It is typically characterized in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities.

Climatic classifications include the spatial variation of these time-averaged variables. Beginning with the view of local climate as little more than the annual course of long-term averages of surface temperature and precipitation, the concept of climate has broadened and evolved in recent decades in response to the increased understanding of the underlying processes that determine climate and its variability.

- **Climate Change:** (Also called climatic change) is defined as any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer.

It is well known fact that agriculture production is dependent on set of climatic conditions. Each crop requires a particular climate for its growth, development and completion of its life cycle. This is the one of the reason that farmers can cultivate a specific crop in a particular region which is having suitable climatic condition to that crop. For example an apple crop can be cultivated in temperate climatic conditions. The climatic resources which cannot be manipulated by the human beings are the deciding factor for successful cultivation of any crop. The one of these resources includes availability of the water for the crop. The availability of water for irrigation and the source of the water both are climate dependant factors. Both shortage and excess of water will interfere the agriculture production. The latest reports (FAO, 2013) of statistics of utilization of world land says that thirty percent of the earth's land is used for crops and pastures and seventy percent of all abstracted freshwater is directed towards irrigation to produce the food that people and livestock need for a stable food supply. This large-scale utilization of land and water resources is increasingly threatening environments. Furthermore, farming is important because it provides the livelihood of hundreds of millions of people.

Agriculture system in many countries are particularly vulnerable for several reasons like (i) climate already too hot and often too dry; (ii) water supply is limited and variable (iii) low and degraded soil quality and (iv) lack of adaptive capacity because of relatively poor regions and low levels of technology and research and development.

Keeping in the view the challenges for agriculture due to changing climate, the chapter focuses on the impact of climate change on agriculture, knowledge on the relationship between climate change and food security and how agriculture is able to adapt to such climate change. The chapter also explores about the important issues like what will be the impending impact of such change and what mechanisms can be implemented to mitigate the resulting impact? Climate change is expected to affect human livelihood, up to different extents, at different regions on the globe. Each part of agriculture production system may react differently in different climatic situations. The chapter also focuses on the consequences of climate change on different aspects of agriculture such as crop production, livestock, fishery production, biodiversity, pests and diseases, Carbon fertilization, irrigation, food accessibility and utilization. Furthermore, the chapter discuss about the mitigation measures for the climatic change situations. Each aspect of agriculture has to adopt to climate change situations for sustained agricultural production has also been discussed. In order to meet the elevated flow of agricultural production further research and extension activity need to be focused keeping in mind the changing climatic situations. Hence, at the end, the chapter discuss about the latest trends in the agriculture research for changing climatic situations. However, the impact on agriculture and its ability for adaption may vary with different parts of world.

The purpose of the chapter is to enrich the current state of knowledge of readers on the relationship between climate change and food security and nutrition to provide an evidence base discussion. The chapter provides the background of climate change and an analysis of empirical evidence results to highlight the relationship between climate change and different components of food security. A summary of key messages is provided for each section of the chapter.

BACKGROUND

Agriculture is backbone of human survival on the globe. As agriculture and allied activities is highly climate dependant, change in the climatic parameters may severely affect food security on the globe. Lobell and Gourdji (2012) noticed that climate trends over the past few decades have been fairly rapid in many agricultural regions around the world, and increases in atmospheric Carbon Dioxide (CO_2) and Ozone (O_3) levels have also been ubiquitous. The virtual certainty that climate and CO_2 will continue to trend in the future raises many questions related to food security and health. One of the important threats is whether the aggregate productivity of global agriculture will be affected due to climate change.

Many factors will shape global food security over the next few decades. These include changes in rate of human population growth, agricultural productivity, income growth and distribution, dietary preferences and disease incidence. There will be increased demand for land and water resources for other uses like bio-energy production, carbon sequestration, and urban development. In this situation, maintaining increased flow of agricultural production is important to meet the need of growing population and new food habits. The flow of agricultural production for global food security and possibilities for the growth in agricultural productivity are important. The sources of growth in agricultural productivity are multifaceted. This includes levels of funding for public and private research and development, changes in soil quality, availability and cost of mineral fertilizers. Apart from this includes important climatic parameters like atmospheric concentrations of Carbon Dioxide (CO_2) and Ozone (O_3), and changes in temperature (T) and precipitation (P) conditions.

The main question of interest here is: how important will climate change in shaping future crop yields and other agricultural production at the global scale, relative to the many other factors that influence productivity? This question helps to set the challenge of climate change adaptation in context.

Two spatial scales are of primary interest while discussing impacts of climate change on food security. One is the global scale, because most major sources of human calories (e.g. rice [*Oriza sativa]* or maize [*Zea mays*] or wheat [*Triticum aestivum*]) are international commodities whose prices are determined by the balance of global supply and demand. In this context, individual regions are only of interest to the extent that they contribute to global supply. However, it may be equally true that not all areas are fully integrated into global markets. In fact, many of the poorest and most food-insecure areas currently lack the infrastructure and institutions need to fully participate in global (and sometimes even regional) markets.

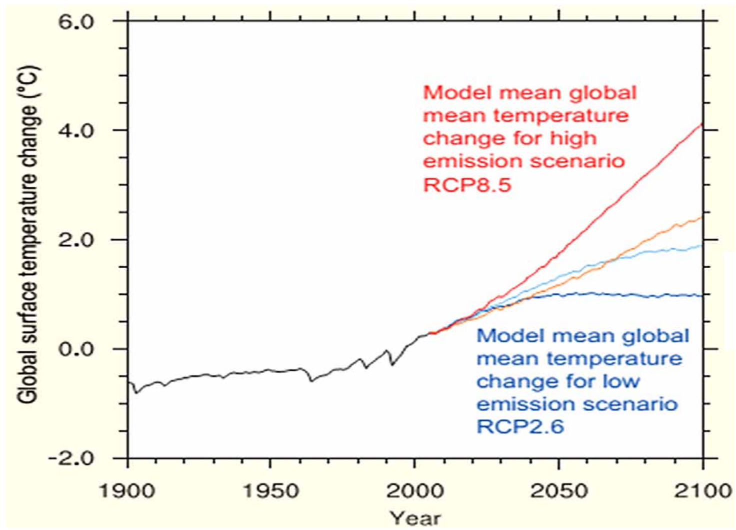
Similarly, climate impact assessments must consider crops and their varieties suitable for the prevailing situations. It may be expected that due to climate change there is possibility of change in climatic regimes and shift in seasons. This will create need to change in cropping patterns in some of the regions.

Furthermore, based on the climatic situations, few crop varieties may need to change in cropping patters in some of the regions. Many researchers reported (Mendelsohn, Nordhaus, and Shaw, 1994) that the direct effects of climate change on crops are expected to occur gradually, allowing controlled adaptation, changes in pest activity may occur quickly and dramatically. So based on the situation more pest and disease resistant short duration crop varieties need to be developed for the future food security. By far, the most common crops considered in published studies to date are (in order) wheat, maize, rice and soybean (White et al., 2011). These crops are the main sources of human and livestock calories globally. They also directly or indirectly (via livestock) provide the bulk of protein in many regions. However, many other foods are important sources of calories (e.g. starchy roots in Africa, non-soybean vegetable oils, and sugar) or protein (e.g. pulses and seafood), yet there is relatively little known about the response of their production to climate change.

Projections of climate change are inherently uncertain, due to the natural variability in the climate system, imperfect ability to model the atmosphere's response to any given emissions scenario. Similarly, difficulties in evaluating appropriate methods to increase the temporal and spatial resolution of outputs from relatively coarse climate models, and the range of possible future emissions (Challinor et al., 2009). There is growing evidence of improved skill of climate models in reproducing climatological features of the global monsoon. Taken in to consideration the recommendations of Intergovernmental Panel on Climate Change (IPCC, 2013) with identified model agreement on future changes, the global monsoon, aggregated over all monsoon systems, is likely to strengthen in the 21st century with increase in its area and intensity, while the monsoon circulation weakens. Monsoon onset dates are likely to become earlier or not to change much and monsoon retreat dates are likely to delay, resulting in lengthening of the monsoon season in many regions. The Predictions of Intergovernmental Panel on Climate Change may further increase the complexity of food security many folds. Again these uncertainties are compounded by the paucity and unreliability of basic information related to agricultural production.

Collins et al. (2013) reported the temperature response by the end of the 21st century for the highest and lowest Representative Concentration Path-

Figure 1. Global mean temperature change for the four Representative Concentration Pathway (RCP) scenarios: RCP 2.6 (dark blue), RCP 4.5 (light blue), RCP 6.0 (orange) and RCP 8.5 (red)
Source: Collins et al. 2013



way (RCP) scenarios (Figure 1). The study using models agree on large-scale patterns of warming at the surface, for example, that the land is going to warm faster than ocean, and the Arctic will warm faster than the tropics. But they differ both in the magnitude of their global response for the same scenario, and in small scale, regional aspects of their response. There is inevitable uncertainties in future external forcing, and the climate system's response to them, which are further complicated by internally generated variability.

CLIMATE CHANGE AND AGRICULTURE

Agriculture is the very basis of civilization. It is practice of farming which includes cultivation of the soil for growing different crops and the rearing of animals to provide food, wool, and other products to sustain human life. The agricultural activity is highly influenced by the weather and climatic conditions. Each crop requires a particular set of soil and climatic conditions for proper growth and development. The agriculture and food security are important variables for intervention under climate change. According to Easterling et al. (2007) a 2°C rise in global mean temperatures by 2100, in the range of the IPCC low emissions (B1) scenario, will destabilize current farming systems. In such situation climate change has the potential to transform food production, especially the patterns and productivity of crop, livestock and fishery systems. This will be having serious consequences on food distribution, markets and access to the food. The interaction of climate change with various aspects within agriculture and their consequences are discussed in following paragraphs.

Food Security

Food is necessary for healthy life of every living organism and defining food security is complex term. According to Food and Agriculture Organization of United Nations (FAO, 2002) Food security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Climate change is playing major role in food security. Climate change may affect staple crop production, especially in the most vulnerable and food insecure countries. Climate change affects food production in multifaceted ways. There may be direct and indirect effects of climate change on food security and livelihood. Direct impacts include changes in agro-ecological conditions of regions where as indirect impacts include changes in economic growth and distribution of incomes. These indirect impacts will in turn affect demand for agricultural produce. Many evidences across the globe suggest that recent increases in temperature have already had a negative effect on yield for some key crops. Furthermore, changes in climate patterns attached with population dynamics may result in higher complexity of food security on the globe. The quality and quantity of cropland available is projected to decrease and there may be decline in land for double and triple crops. Increased levels of temperature and variations in precipitation due to anthropogenic greenhouse gas emissions may affect land suitability and crop yields in many countries. Some workers (Vermeulen et al. 2010) have also reported that climate-driven price fluctuations can lead to acute food insecurity for the relatively poor who spend most of their incomes on food.

Food security is directly or indirectly depends upon availability of sufficient quantity of quality water. So water is one of the main factors for agricultural production both is closely interlinked. Globally, over 80% of all agriculture is rain-fed and the shift in mean precipitation patterns will affect vulnerable rain-fed agricultural areas. This gives clear indications that water resources in future may be strongly impacted by climate change, with wide-ranging consequences for both human societies as well as agricultural ecosystems. The inadequate quantity of quality water may lead to insufficient food production, other socio-economic and health related problems. The shortage of food production may lead to rise in food prices and can exacerbate under nutrition and health may be impacted through changing disease patterns. The broad consequences of climate change on food security are given in table 1 and impact of climate change on food security in table 2.

Crop Yields

Agriculture and the crop production is possibly the sector may be most affected by climate change, but impact assessments differ and thus are difficult to compare. Developing countries seems to be more affected as reported by researchers (Lifson and Mitchum 2013), are more likely to see a drop in agricultural productivity and increased food prices due to climate change, particularly in tropical regions. In areas where limitation of water, the impact may be more serious and farmers may be forced to shift from irrigated to rain-watered crops. If we compare the predictions of multiple models, it is giving clear indications with more confidence that future climatic effects on crop production are serious.

According to IPCC Assessment Report 5 (IPCC 2013) the effects of climate change on crop and food production are evident in several regions of the world. Negative impacts of climate trends have been more common than positive ones. Changes in climate and CO_2 concentration will enhance the distribution and increase the competiveness of agronomically important and invasive weeds. All aspects of food security including crop production will potentially affected by climate change, including food access, utilization, and price stability. Nutritional quality of food and fodder, including protein and micronutrients, is negatively affected by elevated CO_2, but these effects may be counteracted by effects of other aspects of climate change.

Climate change may increase progressively the inter-annual variability of crop yields in many regions. Results from various models (Porter et

Table 1. Consequences of climate change and food security

Sr. No.	Food Security Dimension	Consequences of Climate Change
1	Availability (sufficient quantity of food for consumption)	Reduced agricultural production in some areas locally (especially at tropical latitudes)
		Changes in the suitability of land for crop production
		Changes in precipitation patterns could affect the sustainability of rain-fed agriculture in some areas
		Increase in temperature could lead to longer growing seasons in temperate regions and reduced frost damage
		CO_2 fertilization could increase yields for those crops with the physiology to benefit from CO_2 enrichment
2	Access (ability to obtain food regularly through own production or purchase)	Lower yields in some areas could result in higher food prices
		Loss of income due to the potential increase in damage to agricultural production
3	Stability (risk of losing access to resources required to consume food)	Instability of food supplies due to an increase in extreme events
		Instability of incomes from agriculture
4	Utilization (quality and safety of food, including nutritional aspects)	Food security and health impacts include increased malnutrition
		Ability to utilize food might decrease where changes in climate increase disease
		Impact on food safety due to changes in pests and water pollution

Source: (Anonymous 2012)

Table 2. Climate change fact and impact on food security

Sr. No.	Fact	Effect
1	Food prices	Farming families may benefit from higher food prices—as long as they earn more from their crops than they spend on food. But many small-scale farmers actually spend more on food than they earn from selling food
2	Pathways from climate change	The causal pathways from climate change to the various aspects of food security such as food availability, access, utilization and stability are complex
		Increased frequency and intensity of extreme climatic events such as heat waves, droughts, storms, cyclones, hurricanes and floods
		Decrease of fresh water resources and the impacts of temperature increase and water scarcity on plant or animal physiology
		Sea-level rise and the flooding of coastal lands, leading to salinization and/or contamination of water, agricultural lands and food
		Beneficial effects to crop production through CO_2 ‘‘fertilization”
3	Water and food hygiene and sanitation	More influence of diseases and pest species and on plant and livestock
		Damage to forestry, livestock, fisheries and aquaculture

Source: Hertel and Rosch (2010) and Tirado et al. (2010)

al. 2014) suggests that, without adaptation, local temperature increases in excess of about 1°C above pre-industrial is projected to have negative effects on yields for the major crops (wheat, rice and maize) in both tropical and temperate regions. There is possibility that individual locations may benefit from increased temperature. With or without adaptation, negative impacts on average crop yields become likely from the 2030s with median yield impacts of 0 to -2% per decade projected for the rest of the century, and after 2050 the risk of more severe impacts increases. These impacts will occur in the context of rising crop demand, which is projected to increase by about 14% per decade until 2050. The projected changes in the crop yield are depicted in the Figure 2 and impact of climate change on crop production in Table 3. Regional effect shows crop production may be consistently and negatively affected by climate change in the future in low latitude countries, while climate change may have positive or negative effects in northern latitudes.

Livestock

Livestock includes cattle, buffalo, pigs, sheep, horses etc. are raised in agricultural settings such as factory farms, family farms, and cattle ranches. Livestock refers to domesticated animals intentionally reared in an agricultural setting to produce food or other products such as leather, wool, milk, etc.

Climate change may be having direct effects on livestock productivity as well as indirectly through changes on the availability of fodder and pastures. Livestock systems in developing countries are characterized by rapid change, driven by factors such as population growth, increases in the demand for livestock products as incomes rise and urbanization (Delgado et al 1999; Thornton et al 2007). Climate change is adding to the considerable development challenges posed by these drivers of change. These changes will be influenced by both supply-side changes in natural resource use as well as market-led demand changes.

The relationships between livestock populations and the environment are complex and complexity may be more in developing countries. While the overall prognosis for climate change impacts on livestock may not favorable. There

Figure 2. Projected changes in crop yield as a function of time. The y-axis indicates percentage of studies and the colors denote percentage change in crop yield. The sum of absolute bar heights in each time period equals 100%. Data are plotted according to the 20-year period in which the centre point of the projection period falls
Source: IPCC, 2014

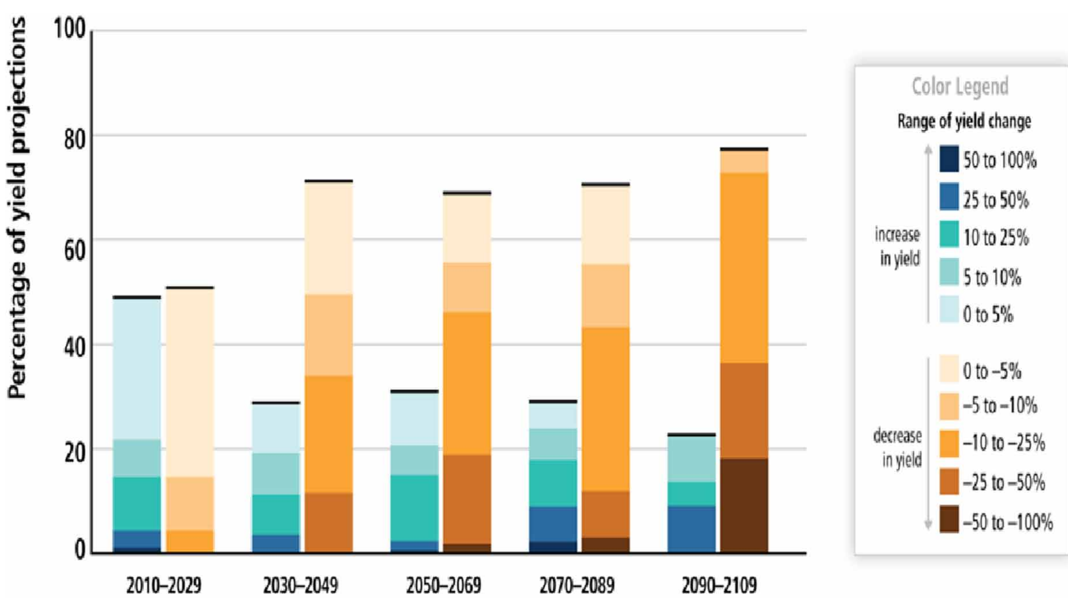


Table 3. Climate change fact and impact on crop production

Sr. No.	Fact	Effect
1	At mid- to high latitudes	Crop productivity may increase slightly for local mean temperature increases of up to 1-3°C, depending on the crop
2	In tropical areas	Productivity will be decreased
3	As climate change progresses	It is increasingly likely that current cropping systems will no longer be viable in many locations
4	Temperatures above 30 degrees Celsius	Each day above 30 degrees Celsius in the growing season reduces the final yield of maize by 1 percent under optimal rain-fed conditions and by 1.7 percent under drought conditions
5	Flooding due to climate variability	Significant problem for rice farming, especially in the lowlands of South and Southeast Asia
		Flooding already affects about 10 to 15 million hectares of rice fields in South and South East Asia, causing an estimated 1 billion USD in yield losses per year
6	Droughts	Many rain-fed rice-growing areas are already drought-prone under present climatic conditions and are likely to experience more intense and more frequent drought events in the future
7	Pests and diseases	Pests and disease that were once minor problems can turn into major constraints and change their range of distribution

Source: Thornton and Cramer (2012), Jones and Thorton (2008), Lobell et al. (2011), Bates et al. (2008), Pandey et al. (2007) and Herrera et al. (2011)

may be possibility of more substantial impacts that will occur in tropical locations.

The livestock production is one of the important components in food security and human needs. But the global livestock sector also contributes a significant share to anthropogenic Green House Gas (GHG) emissions. Food and Agriculture Organization of United Nations (Gerber et al. 2013) reported that with emissions estimated at 7.1 gigatonnes CO_2 -eq per annum, representing 14.5 percent of human-induced GHG emissions. This is the reason why livestock sector plays an important role in climate change. Methane (CH_4) is one of the member of greenhouse gas is a natural by-product of enteric fermentation of the digestive process in animals in which microbes ferment food consumed by the animals. The amount of methane produced and excreted by the animal depends on the animal's digestive system as well as the type of feed they consume.

Regional emissions and production profiles vary widely (Figure 3). Differences are explained by the respective shares of ruminants or monogastrics in total livestock production, and by differences in emission intensities for each product, between regions (Gerbe et al. 2013).

According to US-EPA (2006) report livestock, predominantly ruminants such as cattle and sheep are important sources of CH_4, accounting for about one-third of global anthropogenic emissions of this gas. Current GHG emission rates may escalate in the future due to population growth and changing diets. Greater demand for food may result in higher emissions of CH_4 and Nitrous oxide (N_2O) if there are more livestock and greater use of nitrogen fertilizers. Hence, there is need for reducing enteric methane emissions via improved feeding practices, specific agents and dietary additives, and long term structural and management changes and animal breeding. The overall impact of climate change is mixed and given in Table 4.

Fishery Production

Unlike most terrestrial animals, aquatic animal species used for human consumption are poikilothermic. Their body temperatures vary according to ambient temperatures. So any changes in

Figure 3. Global livestock production and GHG emissions from livestock, by commodity and regions

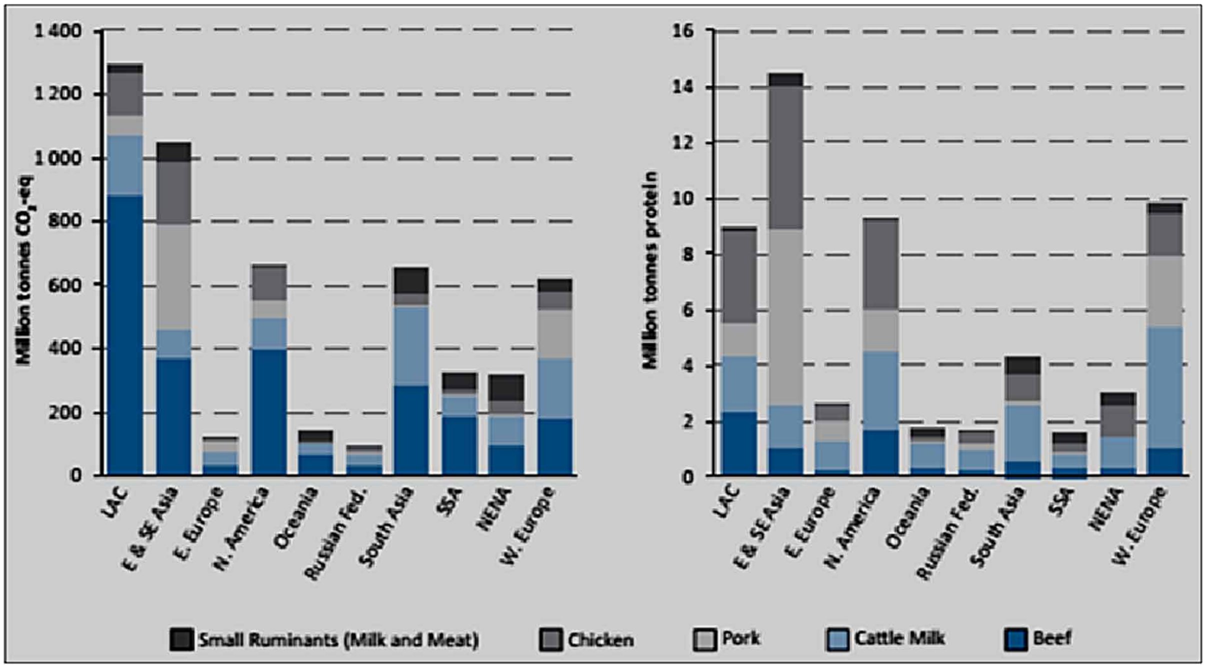


Table 4. Climate change fact and impact on livestock

Sr. No.	Fact	Effect
1	Livestock production	Altering the quantity and quality of feed available for animals
		Expected to change the species composition (and hence biodiversity and genetic resources) of grasslands as well as affect the digestibility and nutritional quality of forage
2	Heat stress	Changes in water availability (with droughts affecting livestock in particular)
		Greater range of livestock diseases and disease carriers
3	Water	Livestock are likely to need more water as temperatures increase
		Droughts and extreme rainfall variability can trigger periods of severe feed scarcity, especially in dry land areas, with devastating effects on livestock populations
4	Increased temperatures	Reductions in the quantity and quality of feed which will lead to less feed intake and higher mortality in certain places
		At higher temperatures animals reduce their feed intake by 3 to 5 percent for each degree of temperature rise
		Impair Livestock reproductive success
5	Distribution of vector-borne livestock diseases	The changes occur as a result of shifts in the geographical ranges of ticks, mosquitoes, flies and other vectors
		Diseases affect include East Coast fever, babesiosis, anaplasmosis and trypanosomiasis
6	Elevated CO_2 + increase in temperature, precipitation and nitrogen deposition	Increased primary productivity in pastures, with changes in species distribution and litter composition
7	Direct impact of climate change	Productivity losses (physiological stress) owing to temperature increases
8	Indirect impact of climate change	Changes in the availability, quality and prices of inputs such as fodder, energy, disease management, housing and water

Source: Thornton et al. (2009), Easterling et al. (2007) and Thornton (2010) habitat temperatures significantly influence their metabolism, growth rate, productivity, seasonal reproduction, and susceptibility to diseases and toxins.

Freshwater aquaculture of many countries is likely to be affected by the climate change and may also be affected by flooding or by drought or high temperatures. There are basic differences in possible effects of global warming on marine and inland fisheries and aquaculture. Marine fish have large population sizes, high fecundity, and often planktonic stages and migration is less restricted. Inland and aquaculture fish will have markedly less opportunity to temporarily escape from warm or oxygen poor water. The distribution and population sizes of marine fish species are already affected by changes in sea temperature. Further, climate change may affect all dimensions of food security from aquatic source due to its impact on habitats, stocks and distribution of key fish species. Projected changes in the variability and seasonality of climate will also impact aquaculture through effects on growth rates and stability of domesticated fish populations. The interaction of changing climate and its some of the consequences on fish production are given in table 5.

Biodiversity

Biodiversity for food and agriculture includes the variability among living organisms contributing to agriculture and food production. This also includes forestry and fisheries sectors which are associated with food security. The biodiversity includes diversity within species, between species and of ecosystems. There are increasing evidences that agricultural biodiversity with the context of food security will be significantly affected by climate change. It is now widely recognized that climate change and biodiversity are interconnected. Biodiversity is affected by climate change, with

Table 5. Climate change fact and impact on fishing

Sr. No.	Fact	Effect
1	Fishing regions	The impact on marine fisheries is expected to differ hugely across the major fishing regions Some regions experiencing a relative decline in catch and others a relative growth
2	Geographic distributions of fish species	Changing geographic distributions of fish species are expected- namely, pole ward expansions of warmer-water species and pole ward contractions of colder-water species
3	Fish habitats	New fish habitats may emerge from polar ice melts
4	Coastal regions	Sea level rise, surges and flooding could have both negative and positive impacts on fish productivity
		Climate change can directly impact fish physiology, potentially changing feeding, migration and breeding behavior
5	Changes in the physical environment (e.g. temperature) of fish	Can alter fish growth, reproductive capacity, mortality and geographic distribution
6	Inland aquaculture (raising fish in captivity)	Likely to be affected by water scarcity or flooding and salinization in coastal regions
	Indirect climate change effects	Alter the productivity, structure and composition of the marine ecosystems that fish rely on for food
7	Ocean warming and acidity	Presents serious food security concern to countries, such as Solomon Islands, that heavily depend on reef fisheries

Source: Cheung et al. (2010), Beare et al. (2004a; 2004b), Easterling et al. (2007), Brander (2010) and Thornton and Cramer (2012) negative consequences for human well-being. Biodiversity, through the ecosystem services also makes an important contribution to climate-change mitigation and adaptation. So, biodiversity become an important element in the development of production strategies, to meet the challenges of climate change. The impacts of climate change on the structure and function of plant and animal communities are widely demonstrated by many researchers.

A very large ecological area on the earth's surface, with fauna and flora (animals and plants) adapting to their environment is called biomes. The multiple components of climate change are anticipated to affect all the levels of biodiversity, from organism to biome levels. Climate change may increase the frequency of sudden damages or suffering a disaster leading to increased Catastrophes frequency. At the same time different species may have less Resilience (capacity to withstand stress and catastrophe). Climate change may also affect biome integrity in terms of ecotypes characteristics, distribution shifts and desertification.

Agricultural production is highly dependent on ecosystem serves. The changing climate may seriously interfere in the ecosystem services and its composition, function and production. The poor ecosystem performance may effect on the different ecosystem communities. This in turn may have consequences on biomass quantity, erosion, disruptions frequency, energy flux, and matter flux. The situation may affect the interspecies relationships of different species, their distribution and dynamics.

Changes in climate may have adverse effect on phenology and physiology of the species. There may be possibility of genetic changes due to the situations. The probable genetic changes may include heterozygosis richness, allelic diversity, natural selection, and mutation rates. So in the nut cell there may be very complicated and unpredicted changes in the ecosystem and biodiversity.

Pests and Diseases

Plant pests, which include insects, pathogens and weeds, continue to be one of the biggest constraints to food and agricultural production. The interactions between crops, pests and pathogens are complex and climate dependent. Researchers reported (Gregory et al. 2009) growing evidence that climatic variations and change are already influencing the distribution and virulence of crop pests and diseases. This will also have significant impacts on the emergence, spread and distribution of crop and livestock diseases through various pathways. The new equilibrium in crop-pest-pesticide interactions may be established with consequences for food security.

Some regions in the world may experience the milder winters due to climate change which will increase the survival of many frost-sensitive insects. In contrast to this increasing temperatures in some parts of world may create favorable conditions for higher rates of growth and reproduction in insect herbivores. This increasing temperature may allow insects to reach their minimum flight temperature sooner, aiding in increased dispersal capabilities especially in aphids and moths. The changes in temperature regimes may have positive impact on pest and disease pathogens. Crop pests and diseases will be moving towards the poles as temperatures become warmer. Climate change is expected to cause changes in the distributions of species around the world, with an overall shift away from the equator and towards the poles.

Climate change can aid in the dispersal of plant and crop disease. In addition to this an increase in severe weather events such as hurricanes may also catalyze the spread of crop diseases. A local increase in summer precipitation due to climate change may also be responsible for the increase and spread of few plant diseases in some regions of the world. There may be possibility of increased fungal pathogen load on grassland communities in response to climate change events such as increased CO_2, decreased plant diversity, and increased nitrogen deposition. Hence, plant health may suffer under climate change through a variety of mechanisms to enhanced abiotic stress due to mismatches between ecosystems and their climate and the more frequent occurrence of extreme weather events.

Farmers may use more chemicals such as fertilizers, pesticides and fungicides to enhance crop and livestock yields. These higher amounts of chemicals may create adverse effect on ecosystem, human and livestock health. The growing number of pests and diseases may also lead to higher and even unsafe levels of pesticide residue and veterinary drugs in local food supplies.

Carbon Fertilization

There is ongoing debate about the impacts of carbon fertilization on plants and their yields. Carbon dioxide (CO_2) is essential for photosynthesis. The potential for a 'CO_2 fertilization' effect has long been recognized. Intergovernmental Panel on Climate Change (IPCC, 2007), believed that rise in atmospheric carbon dioxide (CO_2) concentration from about 280 PPM before the industrial revolution to about 360 at present. In principle, higher levels of CO_2 should stimulate photosynthesis in certain plants. This is particularly true for C3 plants because increased Carbon Dioxide tends to suppress their photo-respiration. C3 plants make up the majority of species globally and include most crop species, such as wheat, rice, barley, cassava and potato.

The stages of crop development are governed primarily by temperature, time, photoperiod and atmospheric CO_2 concentration. The elevated CO_2 may have some effects on crop phenology. If dates of planting required to be changed because of the climate change, then phenological timing of plants may be affected. The CO_2 fertilization effect begins with enhanced photosynthetic CO_2 fixation. In general reproductive biomass growth as well as vegetative biomass growth may be usually increased by elevated CO_2. However, the harvest index, or the ratio of seed yield to above-ground biomass yield, may be typically lower under elevated CO_2 conditions. Similarly, Carbon:Nitrogen (C:N) ratio of leaves of plants may usually increased under CO_2 enrichment. Plants may acclimate to elevated CO_2 by requiring less rubisco and photo-synthetic apparatus, which may lead to lower nitrogen contents.

Further, temperature increases in a higher CO_2 world may increase overall biomass productivity of vegetative crops like pastures and forages. This may be possible by extending length of the growing season in temperate regions, and by the interaction of CO_2 and temperature in stimulation of vegetative growth. However, CO_2 and temperature interactions appear to be very small or negligible for reproductive processes (seed set and seed yield).

Under elevated CO_2, stomatal conductance in most plant species may decrease which may result in less transpiration per unit leaf area. However, leaf area index of some crops may also increase. Water-use efficiency (WUE) may increase under higher CO_2 conditions. This increase is caused more by increased photosynthesis than it is by a reduction of water loss through partially closed stomata. Thus, more biomass may be produced per unit of water used, although a crop would still require almost as much water from sowing to final harvest.

In general, predictions from crop models show that increased CO_2 should increase productivity of C_3 plants, but the associated predictions of temperature rise may be detrimental.

Irrigation

Irrigated land area is important for food secure world. These lands provide about 40% of global food production from just 18% of cropland and accounted for about 90% of global freshwater consumption during the past century (Khan and Hanjra 2009). Discussion on irrigation requirement in light of climate change is especially important for irrigated agriculture, as it supports a large part of the world's food supply, while being vulnerable to water scarcity.

While considering the effect of climate change on irrigated agriculture, one must recognize source of irrigation water which is mainly from rivers, aquifers and wells. These sources are highly dependent on precipitation, temperature, and evaporation. These sources are expected to alter river runoff and surface water supplies.

Generally, runoff is likely to decrease in semi-arid regions that depend on irrigation for crop production. Furthermore, areas that depend on snowmelt are particularly vulnerable to rising temperatures and shifts in runoff seasonality. Reduced surface water supply may in turn put increased pressure on limited groundwater resources which may increase the risks of groundwater depletion, land subsidence resource degradation by soil and groundwater salinization. Similarly, as sea level rises due to climate change will create threat for coastal aquifers and salt water intrusion in the agricultural lands. Apart from this climate change may also impact the delivery and effectiveness of irrigation water.

The research evidence predicts that increase in precipitation variability, coupled with higher evapotranspiration under hotter mean temperatures. This implies longer drought periods and would therefore lead to an increase in irrigation requirements, even if total precipitation during the growing season remained constant. It is also anticipated that more frequent extreme weather events under climate change may damage infrastructure (Vermeulen et al. 2010).

Water deficit stress may occur as precipitation does not adequately compensate for an increased evaporation and transpiration demands due to rise in temperature. Overall, global climate change may have serious impacts on water resources and agriculture in the future. This water stress may cause a decline in yield or require more irrigation to maintain yields.

Food Accessibility and Utilization

The threat that climate changes pose to agricultural production does not only cover the area of crop husbandry but also includes livestock and in fact the total agricultural production. Climate change impacts the four key dimensions of food security, namely food availability, food stability, food accessibility, and food utilization.

The availability of agricultural products is directly affected by climate change through its impacts on crop yields, crop pests and diseases, soil fertility and water-holding properties. Whereas, climate change indirectly affect the food security through its impacts on economic growth, income distribution, and agricultural demand.

Stability of crop yields and food supplies is negatively affected by variable adverse weather conditions. Physical, economic, and social access to food may be affected negatively due to climate change. The reason for this may be declines of agricultural production, rise in food prices and lesser purchasing power.

Climate change in coming years may poses threats to food utilization. Climate change may also affect the ability of individuals to use food effectively. This is because prices of most cereals may rise significantly due to climatic changes. At the same time, there are reports indicating that the nutritional value of food, especially cereals, may also be affected by climate change. Overall this may be having serious impacts on human health.

MITIGATION

Mitigation is human intervention to reduce the extent of climate change. It includes strategies to reduce greenhouse gas sources and emissions, and enhancing greenhouse gas sinks.

Looking in to the challenge of climate change, it is clear that there will be serious adverse impact of climate change in future affecting the agriculture sector. Many of the trends and impacts may be highly uncertain at a range of spatial and temporal scales. This may be having adverse effect on food security and human health. Apart from all these negativities the agriculture also presents untapped opportunities for mitigation, given the large land area under crops, rangeland, and aquaculture.

Mitigation of climate change involves actions to reduce greenhouse gas emissions and sequester or store Carbon in the ecosystem. The sequestration of the Carbon could be the short term, and development choices that will lead to low emissions in the long term. The mitigation of climate change can be achieved by investing in wider adaptation of best practices in the food and agriculture. These practices can include the following.

1. **Reducing Emissions of Green House Gases:** The greenhouse gases include CO_2, methane and nitrous oxide. In order to keep green gases under the limit, there is need to adopt the ways for reducing emission of greenhouse gases. The greenhouse gases can be kept under control by using following ways.

    a. The practices that will help to reduce Carbon Dioxide (CO_2) levels:
        i. Land conversion
        ii. Reduced deforestation
        iii. Improved ways to manage wildfires and
        iv. Alternatives to the burning of crop residues
    b. The practices that will help to reduce methane and nitrous oxide levels:
        i. Improved nutrition for ruminant livestock
        ii. Efficient management of livestock waste
        iii. Efficient management of irrigation water on rice fields
        iv. Efficient applications of nitrogen fertilizer on cultivated fields and
        v. Reclamation of treated municipal wastewater for aquifer recharge and irrigation

The mitigation practice may also include reduction of emissions from commercial fishing operations and more efficient energy use by forest dwellers, commercial agriculture and agro-industries.

2. **Sequestering Carbon:** Higher levels of atmospheric CO_2 is having major role in misbalancing the proportion of gases. So it is necessary to have proper balance of CO_2 in the atmosphere. This can be achieved by fixing the excess quantity of CO_2 in the ecosystem. This can be achieved through effective sequestering Carbon. Following are the ways for sequestering carbon in the ecosystem.

    a. Improved management of soil organic matter.
    b. Conservation agriculture involving permanent organic soil cover.
    c. Minimum mechanical soil disturbance.
    d. Appropriate crop rotation.
    e. Reduced use of fossil fuel.
    f. Improved management of pastures.
    g. Sustainable grazing practices on natural grasslands.
    h. Introduction of integrated agro-forestry systems.
    i. Proper use of degraded and marginal lands, and
    j. Planting of carbon sink trees.

ADAPTATIONS

- **Adaptation:** Adaptation is process or action of adjusting to different circumstances or conditions, in this case as a result of a changing climate.

It is clear from the above discussions that there will be uncertainties about the earth's climate. The present methodologies of agriculture production may not effective in changed climate. Hence, for sustainable agriculture production in projected climate changes will require modifications in the form of adaptations. The actions towards adaptation fall into following two broad overlapping areas:

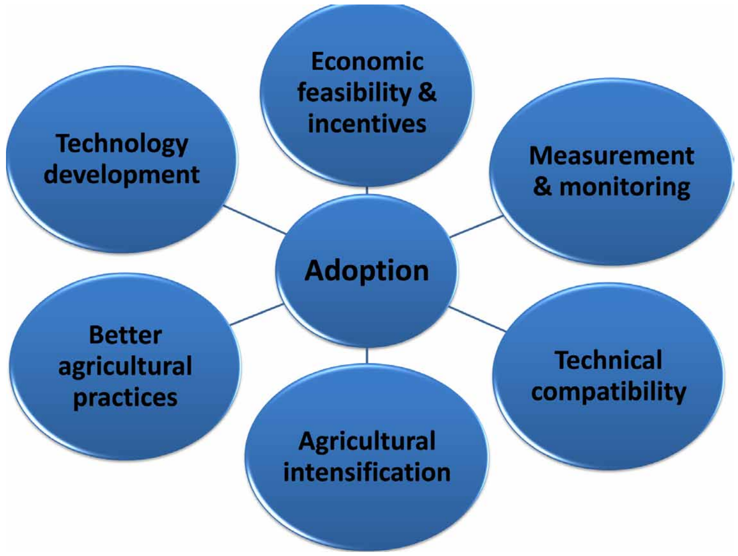
1. Better management of agricultural risks associated with increasing climate variability and extreme events such as improved climate information services and safety nets and
2. Accelerated adaptation to progressive climate change over decadal time scales such as integrated packages of technology, agronomy and policy options for farmers and food systems.

The major challenge may be to enable accelerated adaptation without threatening sensitive biodiversity as they strive to cope with stress. Accomplishing this complicated task requires a multi-pronged strategy. This strategy may include analysis of farming and food systems, learning from community-based approaches, generation and use of new technologies, diversification of production systems, improved institutional settings, enabling policies, and infrastructural improvements.

There is possibility of adaptation in all the sectors of agriculture at multiple levels. Based on the area and situations many options that are technologically, economically and socially feasible are now emerging. Some of the adaptation options are outlined in figure 4 and discussed in below paragraphs.

- **Technology Development:** It is necessary to develop newer technologies to coup with climate change. This may include management of abiotic stresses in crops. The crop breeding and development of transgenic crops supported by biotechnology is required. It may also include investment in crop improvement to address specific characteristics such as heat, drought, water logging, pest resistance, etc. of a progressively changing climatic situation. Following are the some of the adaptation and/or mitigation actions may be kept in mind while developing technologies.
  - Selection of plants that can better utilize carbohydrates which are produced when plants are grown at elevated CO_2
  - Selection of plants that produce less structural matter and more reproductive capacity under CO_2 enrichment (This applies for seed crop plants, not necessarily vegetative biomass plants)
  - Search for germplasms that are adapted to higher day and night temperatures, and incorporate those traits into desirable crop production cultivars to improve flowering and seed set
  - Change planting dates and other crop management procedures to optimize yields under new climatic conditions, and select for cultivars that are adapted to these changed agricultural practices
  - Shift to species that have more stable production under high temperatures or drought
  - Determine whether more favourable N:C ratios can be attained in forage cultivars adapted to elevated CO_2
  - Where needed, and where possible, develop irrigation systems for crops

Figure 4. Possible adaptation options



- **Better Agricultural Practices:** The experience of present farming systems are adapted to the current climate conditions that farmer's experience. But the climatic situation on the earth is going to change in near future. So, changes in farming practices suitable in changing climate may help in sustainable agriculture production. While switching over the practices, it should meet projected food needs with changing population and food habits of the society. Following issues need to be addressed in order to meet the challenge of food security in climate change situation. This will require innovation and capacity building in each issue as they are new to the society.
    - Opportunities for sustainably intensifying agricultural production and avoiding conversion of high carbon landscapes,
    - Technical compatibility of food production and measures that reduce or sequester GHGs
    - Need for inexpensive, on-farm measurement and monitoring to test real GHGs budgets and
    - Economic feasibility of incentives for changing farming practices without compromising investments in food security
- **Agricultural Intensification:** Agricultural intensification is the increase of yields per unit land area is assumed necessary to meet projected food needs of current economic and dietary trends. Producing more crops from less land is the single most significant means of achieving food production in agriculture. The assumption behind is that the resulting spared of land may sequesters more carbon or emits fewer GHGs than farm land. The proposed agricultural intensification will require more attention to the efficiency of inputs and their environmental consequences. Agricultural intensification will require appropriate institutional and policy support to create environmental benefits as well as increases in crop yields.
- **Technical Compatibility:** The major aim of technical compatibility is to reduce GHG emissions or sequester more carbon without reducing food production. Individual climate compatible develop-

ment programmes may include distributed renewable energy that benefits health by reducing dependence on charcoal burning and provides opportunities for livelihood diversification. Additionally, cash-for-work social protection programmes may be introduced to encourage work on local adaptation and mitigation programmes.

- **Measurement and Monitoring:** Suitable mitigation measures are very important in climate change scenarios. Mitigation measures may potentially affect the cost, yields and sustainability of food. It is essential to get more precise estimates of mitigation and its related effects on food systems. But mitigation potentials may also uncertain in nature as most have been estimated through highly aggregated data. Apart from this in low-income countries, greenhouse gas budgets at the local and national levels for specific farm practices, foods and landscapes may often unavailable. Full accounting of GHGs across all land uses will be necessary to account for leakage and monitor the impacts of intensification.

Economic feasibility and incentives: Economic feasibility of agricultural mitigation should be explained in detail and its links to investments in food security also needs to be explained in better way. There should be certainty in carbon prices. It will be beneficial to the farmers and others who will drive for the expansion of cultivated areas with incentives to undertake mitigation practices. The potential for mitigation through alternative agricultural development pathways and the incentives driving them may be important for transforming agriculture towards more sustainable practices. While doing this greater investment may be needed in the capacity of rural communities to access, interpret and act on climate-related information. The role of the public-private partnerships will be important while dealing with food security and climate change challenges.

FUTURE RESEARCH DIRECTIONS

There is uncertainty about the future climate on different parts of the globe. Better understanding of past, recent and possible future changes in the climate is an important element for developing adaptation responses. These adaptations should ideally be targeted at locally relevant climate impacts and risks. The information provided in the chapter is of value to a wide range of different stakeholders in agriculture sector eager to learn more about future weather and climate of the Earth and its consequences on food security. In terms of the future climate, the chapter provides the effect of different climate variables on the various agriculture sectors. Nevertheless, there is broad agreement that the climate is set to shift significantly, and that adaptation responses are needed in order to meet the growing demand of food.

The food supply is coming through agriculture production from agriculture ecosystem which is very fragile and complex in nature. Each component of this fragile ecosystem is important, so its behavior in changing climate is crucial. The detailed research on each aspect of agriculture contributing in food supply along with its relationship with other parameters in the ecosystem could be important emerging research trend. The research on the individual crop varieties suitable for changing climatic situation is necessary. This includes high yielding varieties; resistance to pest and diseases, salt tolerance, drought resistance, short duration, etc. is required. The future scope of plant and animal breeding is vast. Hence role of research in biotechnology and breeding needs to be strengthened in the future. Similarly, land and water availability, soil quality and interactions of soil microorganisms to supply sufficient nutrient in changing climate could be a research interest of the scientists in future. However in coming years the literature on all these topics is essential for sustainable agriculture production.

CONCLUSION

There are many pathways through which climate change will impact food availability, access, and utilization. Climate induced changes in agricultural productivity will likely affect the incomes earned and the food prices faced by poor house-holds. This will have the net effect on food security and livelihood strategies. In addition, health impacts associated with climate change could hamper the ability of individuals to utilize food effectively.

The aggregate impact of climate change on food security is not fully understood. The changing climate is having important role in agriculture production and individual climatic parameters and their interactions are equally important. There is an emerging consensus that changes in temperature and precipitation can have detrimental impacts on the food, in the absence of adaptation. Several of the impacts are difficult to quantify and depend on a range of assumptions. The available quantitative scientific studies suggest that climate change may negatively affect food security at the global level in the coming future. The climate change may reduce crop yields and the land suitable for agricultural production with the greatest impacts in tropical latitudes where the greatest food security challenges persist. Food prices will increase as a result of climate change, thereby affecting the ability of poor farmers to purchase food. Climate change will be having impact on different health problems, pest and disease patterns which will also affect the ability of the body to absorb and utilize nutrients.

Overall, the climate change may be having positive as well as negative effect on the agriculture production and food security of the world. This will be the greatest challenge on the globe. It will require proper mitigations and adaptations for food secure world.

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KEY TERMS AND DEFINITIONS

Adaptation: Adaptation is the process by which living organisms' changes to become better suited to survive in their environment. Adaptation can be a physical or genetic trait that helps an organism to be better suited to survive in the environment.

Biodiversity: Biodiversity refers to the means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

Biome: Biome is very large ecological areas on the earth's surface, which includes fauna and flora (animals and plants) adapting to their environment.

Climate Change: Climate change refers to any significant change in the measures of climate parameters lasting for an extended period of time. Climate change includes major *changes* in temperature, precipitation, or wind patterns, among other effects, that prevailing in a region over several decades or longer.

Climate: Climate can be defined as an area's long-term weather patterns. It can be described as average temperature and precipitation over a period of time. The useful elements for describing climate include the type and the timing of precipitation, amount of sunshine, average wind speeds and directions, number of days above freezing, weather extremes, and local geography.

Mitigation: Mitigation in the context of climate change is an intervention intended to reduce adverse human influence on the climate system which includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.

Resilience: Resilience is the capacity of organism or system to withstand stress and catastrophe. In case of climate change the capacity of crop and livestock to withstand and sustain in the changing environment is the resilience.

Chapter 20
Impact of Rapid Urbanization and Climate Change on Agricultural Productivity in Africa:
Climate Change Policies in the Agricultural Sector

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ABSTRACT

Africa continues to experience serious signs of multiple crises in the context of sustainability. These crises include vulnerability to climate change, rapid urbanization, food insecurity, and many others. One crisis, that defines Africa today, is the unprecedented rapid urbanization which continues to pose a big challenge to the diminishing available resources, environmental quality and human well-being. Cities in Africa continue to experience a fast horizontal growth of settlements due to influx of people from rural areas who often settle in the economically lowest segments in urban areas. This horizontal rapid growth has eaten up land set for agriculture around cities and promoted the rapid growth of informal settlements exacerbating the impacts of climate change leading to a negative impact on agricultural production. Policies linking rapid urbanization and climate change with agricultural productivity are need. This paper explores and documents the impact of rapid urbanization on climate change policies and subsequent impact on agriculture in Africa.

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1. INTRODUCTION

Today, Africa continues to receive more and more attention because of the increasingly enormous deep-rooted and complex sustainability challenges the continent faces. The region has experienced serious signs of multiple crises in the context of sustainability. These crises include vulnerability to climate change, depletion of natural resources, food insecurity, governance problems, conflicts, poverty, and many others (Mutisya & Nagao, 2014; Mutisya & Yarime, 2011). These crises emanate from Africa's unsustainable development and growth, and have threatened the current human systems. One unsustainable growth path, that defines Africa today and that will continue to receive a lot of attention, is the unprecedented rapid urbanization. Africa's urban population is rapidly increasing posing a big challenge to the diminishing available resources, environmental quality and human well-being (Mutisya & Yarime, 2013). This increase is not accompanied by concomitant socio-economic growth and environmental development.

Discourse on rapid urbanization indicates that, although cities in Africa occupy a small percentage (4%) of land, a bigger population in the continent live in cities (Potts 2012; Seto et al. 2011, Shuaib et al, 2012). As START (2011) documents, Africa is characterized by the historical mix of urban development pathways, and the region's cities are described as having grown in pseudo manner with ruralization of urban lifestyles, particularly with respect to agriculture in cities (Maxwell 1999; Binns & Lynch 1998; UN-Habitat 2009). How urbanization evolves in Africa in the coming years will determine where agricultural and food baskets in each country will be situated, areas that have traditionally been left to rural regions.

Cities in Africa continue to experience a fast horizontal growth of settlements due to influx of people from rural areas who often settle in the economically lowest segments in urban areas. This horizontal rapid growth has eaten up land set for agriculture around cities and promoted the rapid growth of informal settlements/slums exacerbating the impacts of climate change leading to a negative impact on agricultural production. Particularly because of their role as centers of economic growth, cities house industrial sectors, as well as infrastructures that support mobility of people and locomotives, activities that are major sources of greenhouse gas emissions.

Agriculture and food security as well as the distribution of populations and settlements in cities are some of the major areas likely to feel the greatest impacts of climate change. Due to its capacity to address these challenges and the lack of policies on climate change and agriculture, Africa is considered to be particularly vulnerable to climate change-induced effects (Eriksen et al 2008, IPCC 2007). This requires the formulation of well-thought and articulated climate change policies at regional and national level linking rapid urbanization and climate change with agricultural productivity. However, to formulate these policies, a clear assessment of the impact of rapid urbanization and climate change on agricultural productivity is needed. Previous discourse has focused on the impact of climate change on agriculture as well as the impact of rapid urbanization on agriculture (Binns & Lynch, 1998; Atkinson, 2000; Ayindea, 2011; UNEP, 2011; Shuaib et al, 2012; Calzadilla, 2013). The nexus between rapid urbanization, climate change and agriculture in Africa has not been studied. This paper explores, examines and documents the impact of rapid urbanization on climate change policies and subsequent impact on agriculture in Africa. This will involve the exploration and understanding of the link between rapid urbanization and climate change and its impact on agriculture based on existing policies and strategies.

2. RAPID URBANIZATION AND CLIMATE CHANGE

Climate change in Africa is shaped by the inter-tropical convergence zone, seasonal monsoons in East and West Africa, and the multi-year El Nino/ La Nina Southern Oscillation (ENSO) phenomenon in which changes in Pacific Ocean temperatures indirectly affect African weather (Conway, 2009). These processes influence temperatures and precipitation across the continent including extreme events like meteorological droughts, as well as severe floods. Climate records indicate a warming trend over Africa during the 20th Century, continuing at a slightly faster pace in the first decade of the 21st Century, independently of ENSO impacts (Collins 2011; Nicholson et al. 2013). The growing increase in temperatures is exacerbated by economic activities brought about by rapid urbanization. Industrial parks in cities and the growth of infrastructure remain major contributors to climate change through emission of greenhouse gases (Barrios, Bertinelli and Strobl, 2006).

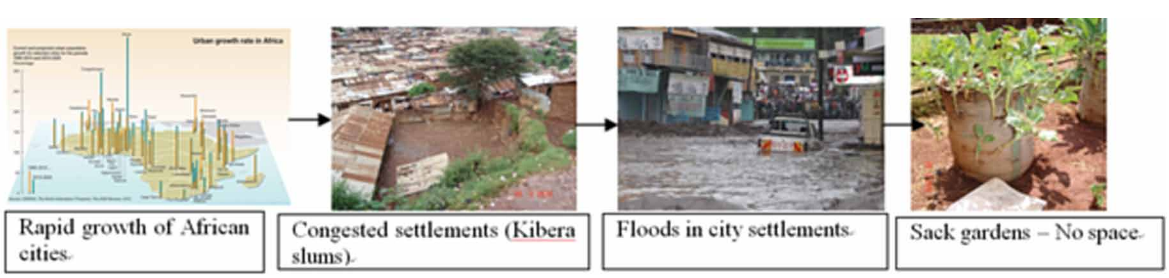
Predictions and reactions to climate change range from aggressive mitigation of greenhouse gases to a continuation of the current trends. Although there is fairly broad consensus about global average temperature trends, regional scenarios of temperature and particularly of precipitation patterns remain quite uncertain. Researchers from the Potsdam Institute for Climate Impact Research recently reviewed the predictions of a number of credible climate models for regional climate change in Africa (World Bank, 2013). Based on climate change projections, average temperature is expected to increase by 1.5°C by 2050 in Africa under an optimistic (2°C) global warming scenario. Falling precipitation and rising temperatures would likely worsen agricultural growing conditions in large parts of Africa (World Bank, 2013).

Under these threats, new agricultural techniques and adaptation practices have evolved, like the evolvement of sack gardens in slum areas in Kenya (as shown in the Figure 1) to meet the ever-increasing urban food demand, and to support urban livelihoods. The evolution of these adaptation methods in the face of rapid urbanization and climate change will continue to expand to meet the ever-increasing socio-economic and environmental demands in Africa.

3. AGRICULTURAL PRODUCTIVITY IN THE CONTEXT OF RAPID URBANIZATION AND CLIMATE CHANGE

Previous studies have already studied the challenges posed by rapid urbanization on sustainable urban development in Africa (Maxwell 1999; Binns & Lynch 1998; UN-Habitat 2009; Mutisya & Yarime, 2013). These studies have identified declining agricultural productivity as a consequence of expansion of cities. In addition, uncontrolled

Figure 1. New urban agricultural techniques

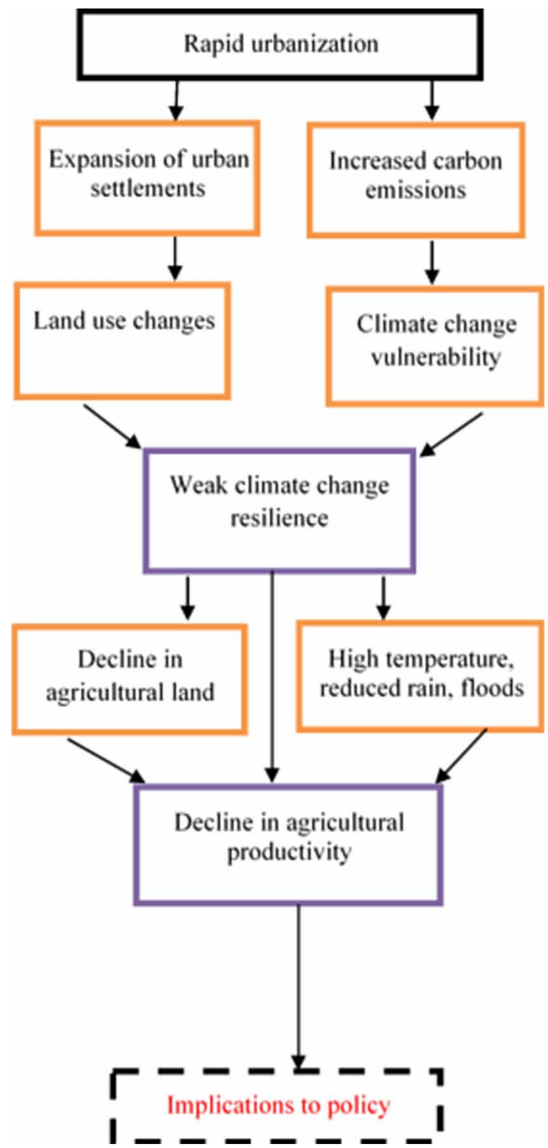


rapid urban growth has been blamed for increasing vulnerability to climate change with adverse effects on urban areas leading to a negative impact on urban livelihoods. These studies find that food security in urban and peri-urban areas remains a challenge in Africa due to the rapidly growing population of urban poor settlements that occupy land traditionally demarcated for agricultural production (Mutisya & Yarime, 2014).

Discourse on rapid urbanization indicates that a rapid growth of cities leads to an increased demand for urban services and this triggers significant transformations of urban and peri-urban environments to rural hinterlands, as the ecological footprints of urban areas increase (Mkwambisi et al. 2011). This has created a change of focus in food security as countries try to balance rural development which remains critical in agriculture-based economies; and rapid urban industrial development which is and will be the principal source of growth for the national economy (Cohen & Garrett, 2010). However, rapid urbanization leads to growth of industries and expansion of settlements that further lead to vulnerability to climate change as well as less land for agriculture. Previous research has also addressed rapid urbanization, as a possible cause of climate change, and decline in agricultural productivity (Lobell, 2008; Cohen & Garrett, 2010; Seto, 2011). But policies that cover the impact of rapid urbanization and climate change on agriculture in Africa have not been fully documented. Confirming these previous findings, and making projections by evaluating the impact of rapid urbanization on agricultural sustainability and its implications to policy in Africa is therefore important as summarized in Figure 2.

The agricultural sector in Africa continues to experience negative effects of climate change more directly than any other sector. A significant literature on climate change and African agriculture is emerging and helps inform and motivate government policies and strategies. Previous studies predict yield losses for important staple and traded crops of 8 to 15 percent by midcentury, with much higher losses of more than 20 percent and up to 47 percent for individual crops under more pessimistic climate scenarios (Kurukulasuriya et al. 2006, Kurukulasuriya and Mendelsohn 2008; Lobell et al. 2008; Schlenker and Lobell 2010; Thornton, Jones, Ericksen and Challinor 2011; Calzadilla, Zhu, Roudier, Sultan, Quirion and Berg, 2011; and Knox, Hess, Daccache and

Figure 2. Mapping the impact of rapid urbanization and climate change on agricultural sustainability



Wheeler 2012; Rehdanz, Tol and Ringler 2013). It has been difficult to assess potential effects in part because adaptation in the agricultural sector appears to be more difficult in Africa. Fertilizer use, for instance, has stagnated in Africa at low levels since 1980, while it has risen tenfold in Asia and Latin America (Cooper et al. 2013), and only 4 percent of agricultural land is irrigated compared to 18 percent globally (You et al. 2010). Being a long-term phenomenon, rapid urbanization and climate change will require the elaboration of long-term strategies and policies to critically address the increasing threats to agricultural production.

4. COUNTRY-BASED CLIMATE CHANGE STATUS IN AFRICA

4.1. Kenya

Kenya continues to face the uncertainty and potential risks of climate change with the rapid expansion of urban areas. The country's fragile ecosystem is under intensive pressure arising from species migration due to habitat destruction and reduction. Already, almost 50% of the country's key biodiversity warehouse is at risk due to reduced habitat and other human induced pressures (Ochola, 2009). Kenya's vulnerability to climate change is furthermore affected by relatively weak institutional capacity, low resource management capabilities, inadequate technology and information infrastructure as well as land degradation, which combined pose serious hurdles to effective climate change responses and worsens its negative impact on the economy.

Rain-fed agriculture - which accounts for 98 percent of the agricultural activities in the country (FAOSTAT, 2010) - is the backbone of Kenya's economy and is very vulnerable to increasing temperatures, droughts and floods, which reduce productivity. Droughts have resulted in agricultural losses, reduction in water quality and availability and are a major driver of food insecurity in the country. On the other hand, floods lead to large-scale crop destruction, and devastation of food stores, farming equipment as well as erosion of agricultural land (Ochola, 2009). Declining rainfall as shown in Figure 3 as well as increasing temperatures are also negatively affecting the growing of major crops in the Kenya (Otto, 1999).

Therefore, if not proactively addressed, climate change is anticipated to adversely affect the country's sustainable development efforts including its ability to attain the objectives set out in the Government's Vision 2030 development plan.

4.2. Nigeria

Climatic fluctuation is putting Nigeria's agriculture system under serious threat and stress. Studies on the effect of climate change on agricultural productivity have been critical given its impact in changing livelihood patterns in the country (Ayindea et al, 2011; Shuaib, 2012). Nigeria's population has become increasingly urban over time, and population densities are higher in Nigerian cities as compared to other cities in Africa (. This is putting pressure on the productivity of agricultural land in the country. Temperature is projected to increase by 2 - 2.5^{0}C for the average daily maximum during the warmest month (Ayindea et al, 2011). Drastic change in temperatures will adversely affect major staple crops. The continued fluctuation of temperatures as shown in Figure 4 is posing farming challenges at all levels in the country.

Additionally, rain seasons have become quite unpredictable. The amount of rainfall per season too has considerably declined to inadequate levels with growing threats of drought and famine. There is a growing variation in the trend pattern of rainfall as shown in Figure 5.

Putting Figure 4 and 5 into context, temperature change is revealed to exert negative effect while rainfall change exerts positive effect on agricultural productivity as shown in Figure 6. This shows that the change in climate has significant effect on agri-

Figure 3. Rainfall level in Kenya from 1900 to 2009 (Source: UNEP, 2011)

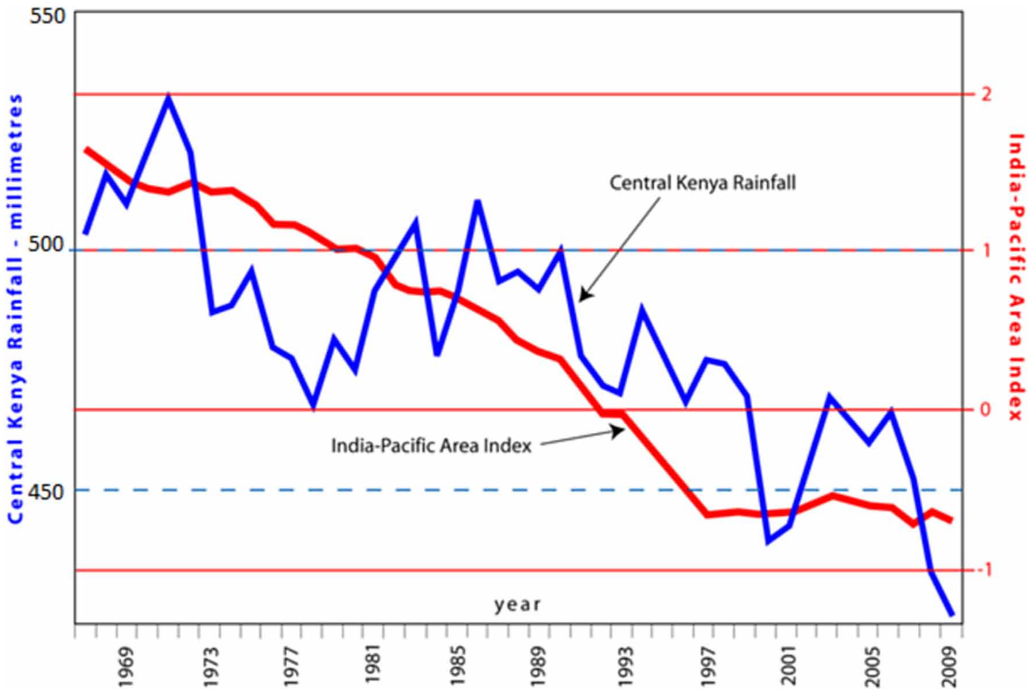
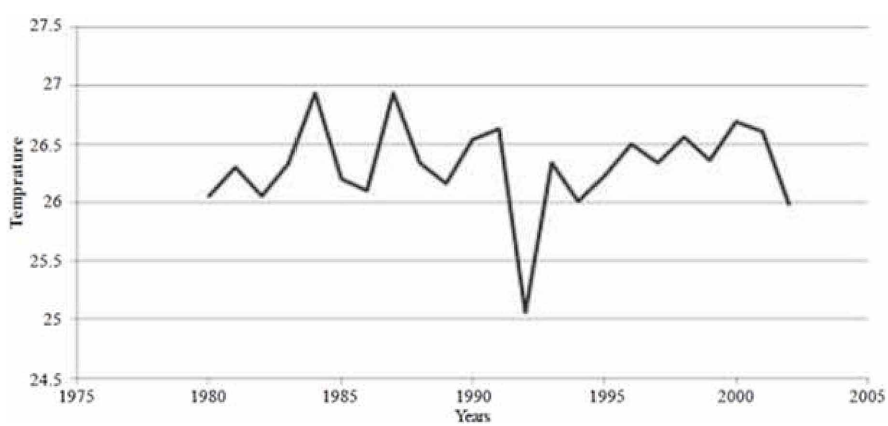


Figure 4. Temperature trend in Nigeria (Source: Ayindea et al, 2011)



cultural productivity. This is clearly revealed in the rainfall variable however temperature seems not an important variable of climate in determinants of agricultural productivity in Nigeria economy (Shuaib et al, 2012, Ayindea et al, 2011).

4.3. South Africa

South Africa remains the most advanced country in Africa when it comes to building capacities to tackle climate change. An important factor in

Figure 5. Rainfall trend in Nigeria (Source: Ayindea et al, 2011)

climate is the enormous existing socio-economic disparity in access to resources, poverty levels, and capacities to adapt in South Africa. Due to rapid urbanization occasioned by economic growth, climate change projections indicate that South Africa will be hit seriously by the negative impacts of increasing temperatures and declining rainfall. The South Africa's case clearly shows that climate change will have two major impacts:

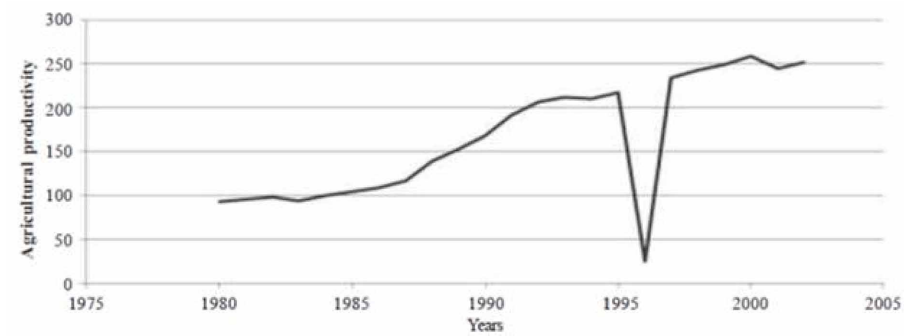
1. Average temperatures will increase. Higher minimum temperatures will have impacts on cold storage, frost frequency, and pest life cycles but will have the advantage of opening up areas to the cultivation of specific crops where it was previously too cold. Higher maximum temperatures will cause more extremely hot days, with increased evaporation, more days of soils drying out, and increased refrigeration requirements for fresh produce. In general, every day after 2050 is likely to be, on average, 2°C warmer than at current temperature levels. This will have severe impacts on seasonal cycles, suitable growing areas, and the way crops grow.
2. The nature of rainfall patterns within seasons will change in both intensity and frequency. This will affect runoff, water availability, the length of dry spells, and the replenishment of groundwater. Agriculture will need to adapt to changes in the areas suitable for specific crops. (Sepo, Gerald, Timothy, and Lindiwe, 2013)

Agricultural production in South Africa is mainly commercial and thus less vulnerable to the impacts of climate change than other parts of the region, because of the capacity to adapt to climate change. Agricultural exports are projected to increase through 2020 and afterward to decline to the point that South Africa will become a net importer of basic agricultural products. It is cause for concern that total production is shown to decline - more dramatically if the scenario's increases in yield do not materialize. Thus climate change is seen to have an anticipated impact on the security of the country's food supply, especially during years of extreme weather (Republic of South Africa, DST 2011).

5. CLIMATE CHANGE AND AGRICULTURE POLICIES IN AFRICA

Africa has not had a clear regional policy on climate change that takes into consideration the current urbanization and agricultural production.

Figure 6. Agricultural productivity index trend in Nigeria (Source: Ayindea et al, 2011)



With the many challenges brought about by rapid urbanization and climate change in the region, a climate change strategy is needed to aid and support regional adaptation and mitigation, foster economic growth and aid other policy strategies. The challenges being experienced in Africa today are happening against this backdrop of the absence of regional and national climate change policies to support sustainable development and especially in the agricultural sector which is one of the core sectors of development in the region. The absence of these policies has negatively impacted on the growth and development of the agricultural sector in the face of rapid urbanization and increasing dangers of climate change and has resulted in spontaneous growth, weak link between rural and urban development and the agricultural sector, uncoordinated initiatives, and weak regulatory capacity and frameworks.

The agricultural sector is a key component of Africa's development because of its contribution to employment and GDP of African countries. Potential adverse impacts of climate change on food production, agricultural and subsistence livelihoods, rural nutrition and food security in Africa are significant policy concerns. In the wake of growing concerns on the impacts of urbanization and climate change on agriculture, African governments are today enacting policies and strategies to address this menace but the implementation of these polices has been put into question. For instance, the African Union has enacted the Climate Change and Desertification strategy which aims to provide policy and political guidance, and to enhance coordination and harmonization of Africa's activities in the field of climate change and desertification within the overall framework of the Climate for Development in Africa. Kenya has developed the National Climate Change Response Strategy while South Africa has enacted the South Africa Climate Change Response Strategy but these policies are too general and do not explicitly address the link between urbanization, climate change and agricultural production.

Therefore, there is a critical need of climate change policies to address the basic challenges posed to the agricultural sector in the face of rapid urbanization. However, even with the enactment of climate change strategies in Africa, the challenges that the agricultural sector faces may not be addressed anytime soon with the current policies. This is because; the realization of Africa's development has been hampered by a fragmented approach to planning as well as a lack of clear implementation plan. There is also a lot of overlapping of different policies as well as duplication of roles by relevant authorities because of competing interests. The current climate change strategies therefore need to be reviewed, re-engineered and harmonized with the impacts of rapid urbanization and the needs of the agricultural sector.

6. CONCLUSION

The impact posed by rapid urbanization and climate change in Africa on agriculture is enormous with increasing growth of urban population, industrial centers and settlements expanding the negative consequences of climate change as well as pushing the rural-urban boundaries outwards leading to a rapid decline of agricultural land. Agricultural productivity remains a key sector in feeding the urban as well as rural populations. However, the sector, which is highly vulnerable to climate change due to its dependence on weather and climate, has been affected negatively by rapid urbanization. To combat these challenges, several policies are being developed in Africa both at regional and national level. This is important because with these challenges, well-thought and articulated climate change policies should be formulated and implemented if the challenges emanating from rapid urbanization and climate change are to be addressed and more important to effectively harness the potentials of the agricultural sector in Africa.

This paper focuses on rapid urbanization and climate change linkages with agriculture in Africa but does not cover the nexus between urbanization, and climate change and its impact on unemployment and income generation as well as the development and growth of industries. Future research could focus on studying these linkages and impacts. Also, future research could document empirically the impact of rapid urbanization and climate change on agricultural productivity using both primary and secondary data from selected case studies. This will help in developing proportionate actions and strategic plans to inform policies for mitigating the negative impacts of rapid urbanization and climate change on agricultural production in Africa.

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Chapter 21
Climate Change Mitigation:
Collective Efforts and Responsibly

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ABSTRACT

Climate change caused due to our careless activities towards our nature, ecosystem, and whole earth system. We are paying and will be paying in future for our irresponsible activities in past and present. Increased concentration of Green House Gases (GHG) has caused severe global warming which will cause melting of glacier and results in sea level rise. To avoid and reduce the intensity and severity of global warming and climate change, its mitigation is essential. In this chapter we have focused on various issues related with climate change and mitigation strategies.

INTRODUCTION

Climate change is a severe problem that world is facing from last few decade as aftereffect of our past activities but we can reduce it by decreasing and changing the root causes for it. Adverse effects of these activities have already substantially ruined our sensitive earth system. Climate changes are occurring primarily due to the anthropogenic activities, which enhance the greenhouse gas concentration, particulate matter concentration, and ecological changes due to drastic change in forest area which ultimately affect the water cycle and affect O_2/CO_2 concentration in the ambient air. Emission of greenhouse gases are increasing day by day and has reached to an alarming stage where a quick and very effective strategy has to be apply on global, regional and local scale to reduce it to a safe limits. There are several social/ economic/ environmental factors which has impact on climate change and vice versa. Efforts of reducing the emission of greenhouse gases especially CO_2 is usually termed as climate change mitigation. Mitigation is a human intrusion to reduce the source or enhance the sinks of GHG. In greenhouse gases, CO_2 is of prime concern because of its severe impact on the climate. Mitigation can be achieved in many ways like reduction in CO_2 emission, use of energy efficient equipments, renewable energy, and behavioral change towards energy consumption. Though it looks quite simple but its implication into practical life will not be that easy. For climate mitigation there are several sectors which should be considered while making mitigation policies

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and these covers the power sector deregulation, energy/oil import security, forestry, industries and rural energy. Utilization of techniques like silviculture or green agriculture in protection of natural carbon sinks as ocean and wooded area is also part of mitigation technique. Purpose of climate mitigation is to reduce harmfulness of climate change; thus has to be part of policies that includes climate impacts adaptation. World need adapt the climate changes and also an efficient strategy for the mitigation policy.

As climate change is global (IPCC 2007, http://climate.nasa.gov/effects/) thus efforts on all the scales i.e. global, regional and local are essential. Thus climate change mitigation policies have to essentially apply on international as well as national level also. In this chapter we will first discuss about the increasing trends of greenhouse gases. This chapter will deal with the current emission situation and future projection from various sources from the current emission scenario i.e. where we are and where we will land with present emission conditions. Various international, regional and national efforts will also we discussed in detail to understand the world approach towards this serious issue. Climate mitigation covers several topics (i.e. transportation efficiency, transport conservation, building efficiency, efficient electricity production, economic costs & benefits, energy security, health and employment, air pollution and several others) under this and we will try to explore each of these in this chapter.

WHAT IS CLIMATE MITIGATION?

Mitigation means an act which reduces the severity of a transgression and in climate mitigation context this term is used for reduction of anthropogenic activities which have spoiled the nature and as a consequence our climate. The Intergovernmental Panel on Climate Change (IPCC 2007) defines "climate change mitigation as technological change and substitution that reduce resource inputs and emissions per unit of output". Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG emissions and enhance sinks. In other words mitigation is a preventive measure to reduce the GHG concentration and limiting the degree of future global warming. Mitigation is different from adaptation which defines the attempt to manage the unavoidable hit of climate change.

Climate change mitigation is an attempt or action executed to reduce the worse effect of our action which has created the danger of substantial increase in global temperature in few decades. Climate mitigation generally means the efforts for reducing the increasing concentration of GHG, especially CO_2. Another way of achieving climate mitigation is to increase the possibility of CO_2 sink which could be achieved by increasing forest and reducing the deforestation. Climate change has global impact and thus efforts should be global instead of national, institutional and individual. Various policies are functional for the climate mitigation at all the levels and collective efforts are impost to achieve this. Instead of very strong determination, there are various limits which still make it difficult to achieve. In this chapter we will be discussing the current situation of GHG concentrations, renewable energy sources, costs and various sectors important for climate mitigations.

As we have discussed earlier in chapter that whole globe should act with same strength for the substantial reduction in GHG concentration. This causes the debate in developed and developing countries as present crisis have occurred primarily because of developed countries GHG emission in the past and present too. Thus as compared to developing countries, developed countries should cut off GHG emission in major proportion. This ideology was embedded in United Nation Framework Convention on Climate Change (UNFCCC) in 1992 and also in Kyoto Protocol in 1997, which put impose on developed country for reduction of GHG emission. Same criteria could not be imposed on developing country due to various limitations which involves socio-economic condition of particular country.

Negotiation started at global level for the reduction in GHG after UNFCCC. Industry, transport and urbanization demands the consumption of energy and Indian utilization of energy contributes ~3.5% in global consumption (Vijiya 2005). To stabilize the GHG concentration in atmosphere, in UNFCCC few essential commitment were made:

1. GHG emission should controlled in such time frame that our environment should get enough time to adjust with climate change.
2. Economic growth should not achieve at the cost of our environment i.e. our economic growth should not worsen the present climate situation.

To reduce the climate change, polices in all fields, i.e. energy, transport, industries, food, human activities, should be implemented. Environmental and energy sources fronts are facing major challenges in present and these are the matter of future concerns as well. With present electricity generation capacity India is lacking energy efficiency and demands more supply of electricity. Use of newer, cleaner technologies, renewable energy sources, reduction in energy consumption, change in nature harming human habits are essential and mandatory steps for climate mitigation.

GREENHOUSE GAS CONCENTRATIONS AND STABILIZATION

In 1990, India was emitter of 3% of global CO_2 equivalent emission which rose to 5% of total GHG emission in 1995 (Vijiya 2005). Whole globe had experienced increase in GHG emission in industrialization period and India is no exception in this. Indian CO_2 emission had increase with a rate of 5.8% from 1950 and in 1990 India's CO_2 had rose by 59.5% and become fifth largest contributor of CO_2 in world. This is as alarming situation and need immediate action. In India emitted CO_2 is primarily coming from coal combustions and fossil fuel burning.

New technologies and alternative energy source can play major role in the reduction of GHG emission in India. Sectors which contributors most to GHG emission involve power, steel, cement, residential and transport; thus use of alternative energy sources and cleaner technologies will show drastic reduction in GHG emissions (Vijiya 2005).

By Sector

In this section we are discussing few important sectors which are primarily responsible for CO_2 emission in atmosphere.

Transport

Transport sector is one of the polluted sector and significant CO_2 emitter. To reduce the CO_2 emission in atmosphere, new techniques have been developed in transport sector. These new revolutionary transport technologies, involves use of hydrogen and electric vehicle. Several researchers worked hard to develop technique by which hydrogen can be used as fuel in vehicles and help to reduce the pollutant and CO_2 concentration in breathing space. Another energy efficient technique in transport in development of electric charge engine which are widely used in motorbikes and cars to reduce the GHG emission. Bicycles are one of the traditional vehicles which are pollution free. Use of all these vehicle types can contribute in reduction of CO_2/GHG in the environment. Though these techniques are pollution free but still a lot has to be done in transport industry as these transport vehicles constitutes only a small fraction in total transport industry.

Building Sectors

GHG emission in building sectors have substantially enhanced from 1970 to 2010 (from 2.5GtCO_2 to 3.2GtCO_2) though contribution from developed countries has decreased. Building sector is seeing more emission from developing countries as compared to developed countries. Building sector CO_2 comes from intensive use of electricity for heating, ventilation, air conditioning and other domestic and commercial needs (UNEP 2009; US DOE 2008). In low income counties per capita emission of CO_2 is high due to intensive use of fossil fuel and biomass burning for cooking and heating needs (IEA 2002; 2006).

Industry

Emission from industries has increased from 6.1 GtCO_2 eq/Yr in 1970 to 10.2 GtCO_2 eq/Yr. In early industrialization period contribution from OECD (Organization of Economic Co-operation and Development) countries were dominating in this emission while after Kyoto protocol a substantial decrease has been noticed in emission from developed countries. But pattern has reversed in low and middle income countries. Developing countries like India, China and Brazil are major emitter of GHG in current scenarios and emission increased by 165% as compared to 2000. Developed countries have adopted much clear, energy efficient and ecofriendly technologies to reduce the GHG emission while developing countries are still using the conventional polluted technologies to fulfill their needs. Increased production of energy intensive industrial product has grown drastically from 1970 to 2012. An increase of 500% in cement production, 400% in aluminum production, 150% in steel production, 250% in ammonia and 200% increase in paper production has been noticed in global annual production and majority of these industries are located in developing countries (USGS 2013; IPCC 2007). From last decade China is dominating in production and export of various products (Weber et al., 2008) and similarly in emission of CO_2.

Mitigation Strategies: Methods and Means

Present climate scenario is result of complex interactions of political, socio-economic, environmental, climatic, and several other known and unknown processes. Thus solution to this problem could not be achieved by just addressing any of these issues alone. All these sectors/issues are interlinked and thus we have to address all the issues simultaneously to achieve earlier climatic situation and clear environment. In this section we will be putting light on various possibilities which can help us in reducing the GHG emission.

TECHNOLOGY TRANSFER

Developing countries are main emitter of GHG these days as developed countries have developed new clearer technologies to reduce the GHG emission while developing countries are struggling for that. Thus a gap exit between developed and developing countries in term of technologies as well as GHG emission and to fill this gap technology transfer is a possible step from developed countries towards developing countries in order to help in climate change mitigation. Technology transfer is also seen as transfer from north to south where north represents Annex I countries and south represents Non-Annex I countries (discussed later in this chapter) (CCMP 2006). Several studies have been performed to study and explore the various aspects related with technology transfer (Forsyth, T., 1999; Kabiraj and Marjit, 1993; Arora, A. & Fosfuri, A., 2003; Morita and Nguyen, 2011). GHG emissions are primarily because of anthropogenic activities and present technologies are also causing tremendous emission of GHG. Thus transformation of older technologies in newer and cleaner technologies plays a crucial role in reduction of GHG emission and this created need of sustainable development technologies. The term coined for technology change is called Technology Transfer and IPCC (IPCC 2000) defined this as:

… a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/ education institutions…

… the broad and inclusive term "transfer" encompasses diffusion of technologies and technology cooperation across and within countries. It covers technology transfer processes between developed countries, developing countries, and countries with economies in transition. It comprises the process of learning to understand, utilize and replicate the technology, including the capacity to choose and adapt to local conditions and integrate it with indigenous technologies.

Three major components which guarantee the success of technology transfer are capacity building, enabling environment and mechanism for technology transfer. National and institutional contributions/efforts, governmental support for the R&D work; industrial support, foreign direct investment (FDI) and official development assistance (ODA) are the prime monetary channel for technology transfer.

Alternative Energy Sources

Renewable Energy

Renewable energy is derived from natural sources which are replenished constantly. Solar light, winds, tidal power, geothermal heat and plant growth are the premium resource of renewable energy. Renewable energy sources are new hopes in view of current climate change situation and to reduce the GHG emission. Renewable energies are also useful as conventional energy sources are polluting the environment and the same time exhausting rapidly. Renewable energy industry and R&D are growing because it is promising energy alternative in order to reduce the carbon emission (IEA, 2008; REN21 2006; UN New 2007; Joel et al., 2008; UNEP, 2007).

Three primary sectors in which renewable energy has replaced the conventional energy sources are power generation, heating water/space and transport. In recent years the global share in electricity generation from renewable sources have increase more than 20% and electricity generation from hydro power is about ~17% (Observ'ER. 2012). Though renewable energy industry have grown beyond expectation but there various limitation which stopping it to become the primary source as well as alternative for conventional energy sources. Cost of the renewable energy is higher as compared to conventional energy sources and at the same time availability of this energy is limited which are the major limitation for becoming these type of energy as primary energy sources. But technologies are developing to reduce the cost and enhance the availability of renewable energy. Now about 30 countries are suppling about 20% of their energy demand from renewable energy. Efforts to reduce the price of renewable energy have increased and nation, public policies, industrial support and political willing are playing major role in this direction.

Global warming and consequences related with it, ecological and economic concerns were the driving force for the extensive use and need of renewable energy. According to scientists till 2050 all existing energy source can be replaced with wind power, solar power and hydropower. In relation to price they stated that renewable energy cost should be reduced as much the present energy cost. This will encourage the use of renewable energy as compared to conventional energy. GHG emission will be reduced drastically within 50 years as solar power generation may fulfill most of the energy requirement according to a projection of 2011 of International Energy Agency. Few European countries, Brazil and New Zealand are frontier countries in renewable energy production; as Iceland produces 100% energy from geothermal energy, Brazil (85%), Austria (62%), New Zealand (65%) and Sweden (71%) produces major portion of their energy (as mentioned in the bracket) from hydropower (REN21, 2010). In addition to these countries fraction of renewable energy in total usable energy is increasing in other countries also as 14% in US state Iowa, in German state of Schleswing Holstein and 20% in Denmark and also in China.

Nuclear Power

These days nuclear power has become the primary source of energy in developed countries. Conventional fossil fuel are main emitter of GHG, thus for clear atmosphere nuclear power are one of the best alternative method. Nuclear fusion concept has been used for the generation of nuclear energy and thus energy minimizing the CO_2 emission in the atmosphere. Uranium and Thorium are widely used nuclear fuel for the generation of nuclear power. As compared to uranium abundance of thorium is four time. Thus use of thorium has been also encouraged as comparison to uranium as it has been found more secure and abundance. Though nuclear process generates tremendous amount of heat and primary source of energy in most of the developed countries but after the nuclear reactor disaster happened in Fukushima, Japan in 2011, question arouse about the reliability and security in nuclear power. In this regard molten salt reactors can play a revolutionary role in nuclear power industry because of its new design i.e. meltdown proof. Function of these reactors can be explained as: in the case of any untoward situation (i.e. power failure, high fuel temperature) bottom of the reactor melts which allows the nuclear fuel to store in a underground tank and by isolating nuclear fuel, intensity and severity of the accident can be reduce to a very small scale. Due to accident took place in 2011 in Fukushima, Japan, lowest nuclear power generation was reported in 2012 according to World Nuclear Association (WNA, 2013). In spite of this incidence, still nuclear energy will remain major contributor of energy resources and will be a good alternative of conventional energy source because of low CO_2 emission. In nuclear power generation there are several issues should be taken care, especially nuclear fuel, nuclear safety and security risks.

Scientists have found that amount of CO_2 emitted from nuclear reactor has a small fraction in total CO_2 emission as compared to conventional energy source and CO_2 emitted in nuclear reactor is comparable with renewable energy (Warner and Heath, 2012). A serious future concern related with nuclear energy is abundance of nuclear fuel, as consumption rate of uranium/thorium ore is faster than rate of formation in earth minerals. Thus nuclear reactor may face a crisis of nuclear fuel in future which will hamper a very efficient and important energy industry with low CO_2 emission.

Energy Efficiency and Conservation

One more effective way of reduction in GHG emission is use energy efficiently and this is called energy efficiency. Efficient and optimal use of energy will reduce the consumption and subsequently demand of energy. To reduce the energy consumption and GHG emission, energy efficiency can be applied to all sectors which include industries, transport, lighting and building. Best example of energy efficiency is increased use of LED lamps in place conventional lamp i.e. an incandescent lamp. Energy efficient has a direct benefit in economy as it cut energy cost.

Sinks of CO_2

In postindustrial period the emission and absorption of CO_2 was balanced in such a way that CO_2 concentration was maintained in safer limits. But after the industrial period, the emissions of CO_2 have increased tremendously while sink source for it are reducing. Urbanization have casted the forests; and deforestation have adverse impact on our earth. Carbon sink defines a natural or artificial reservoir which absorbs excess CO_2 from environment. Forest and oceans are best natural reservoir for CO_2. Forest or ecosystem absorbs the CO_2 and convert it into oxygen and release to environment. While ocean acts as a reservoir of the CO_2. The Antarctic Climate and Ecosystems Cooperative Research Centre (ACE-CRC) found that about one third of the CO_2 emitted by human are suck by ocean by various physical, chemical and biological surfaces (http://www.acecrc.org.au/Research/Southern%20Ocean%20Carbon%20Sink).Though ocean are major sink body of CO_2 but absorption of CO_2 make the ocean water acidic which may affect the ecological system of ocean. Though the magnitude of these effects are not well known but physical and ecological processes which may hampered due to acidification ocean involves respiration, change in nutrients and harmful toxic concentration. It has been reported in CSIRO which concentrated over southern ocean that marine life over that region has significantly affected by excess CO_2 absorption.

Reforestation and Avoided Deforestation

Deforestation has caused huge amount of CO_2 released in atmosphere as it was found that about 20% of total emission of CO_2 was caused because of deforestation in 2007. Deforestation refers the shrinking of forest area and ecosystem on massive scale worldwide and affair of serious concern. At the same time deforestation affect the land properties and also causing the land sliding. Reductions in rainforests are topic of major concern under deforestation and with current rate they will vanish in a century time. Various causes are responsible for deforestation which include requirement of agricultural land, urbanization and industrialization. Farmers cut the forest to get more crop yield and to provide space for cattle. Increased population density is also a major cause for the decrease in forest land and reduction in other ecosystem resources. Forest based industries such as paper industries wood industries; and domestic requirements are also responsible for deforestation. Efficient transport system also requires removals of forest area, as to make the transport easier, roads are required and this decreased the forest sprawl. Deforestation is not always human caused; natural calamities as wild forest fire and livestock overgrazing also prevent growth of younger plants. Foremost drawback of deforestation is in climate change as CO_2 holding capacity of world decrease with decrease in plantation and cause increase in greenhouse effects. Another impact is on diversity of ecosystem; several plants and animals are facing extinction because of decline of forest area (http://www.nature.org/ourinitiatives/urgentissues/global-warming-climate-change/threats-impacts/). Forest also maintains and prevent the water cycle of the earth system by providing the pipelines for rainwater to become ground water, preventing the soil moisture and reducing the drying up of land. In this way, forests prevent land to convert into the deserts. Forest canopy also put a control of the temperature difference during day and night by removing excess sunlight during day time and holding the necessary heat in the night. A quick solution to this issue is stop cutting of tree immediately but long term solution is applying a huge penalty on individual, industries and also on whole population so that they will forced to protect the tree from cutting. At same time educational system should be structured in such a way that each and every person should understand the importance of plants in our life.

Carbon Capture and Storage

Carbon capture and storage (CCS) is a modern way of mitigation of CO_2 in which carbon is captured from power plants and industries and safely stored, in place of releasing it to environment. In this way CO_2 is artificially getting prevented from being in atmosphere and contribute to reduce climate change. According to IPCC, this technique can contributes in between 10-55% in carbon mitigation during next century. IEA has also acknowledged the importance of this technique in CO_2 mitigation process especially in power plants and industries (Robinson, 2010). One drawback with CCS is requirement of more energy than usual to operate a industry/power plant e.g. a power plant need about 40% more energy than normal if it has CCS but at the same time it could eliminate about 90% of CO_2 emission. Norway became first country to apply this technique to its industries and power plants and has reduces its CO_2 emission remarkably.

Geo-Engineering

Geoengineering is a new branch in geosciences which could be used as mitigation tool or policy (Barker et al., 2007). Geoengineering is a branch of geosciences where various engineering and science stream (e.g.) are used to formulate and understand human earth interactions. Geoengineering has wide application in mining, hydraulic fracturing, exploration of oil, water and natural gases, management of hazardous waste material, underground transportation system and various geological applications. Except the various geological and environmental applications Geoengineering is used in climate mitigation also. However, owing to lack of published results which supports its efficiency in reducing the adverse effect of the climate change, IPCC, 2007 says geo-engineering techniques (as ocean fertilization to remove CO_2 from the atmosphere) are largely unreliable. In National Academy of Sciences (1992) Geo-engineering has been defined as an stream of engineering in which large scale engineering has been apply to reduce the climate change adverse effect (PIGW 1992).

In context of climate, geoengineering is defined as utilization if global techniques in natural/ environmental system to subside the impact of climate change. Two widely used geoengineering techniques to mitigate the climate change are solar geoengineering and carbon geoengineering.

In solar Geoengineering, also called solar radiation management, albedo of the earth system is increased artificially to counter balance the increase in temperature owing to increase in GHG. Increased albedo will help our earth system to cool down and compensate for temperature rise. Efficient techniques used to achieve this are albedo enhancement, space reflectors and stratospheric albedo.

Carbon dioxide removal or carbon Geoengineering describes the engineering techniques for reduction of CO_2 from atmosphere and ocean acidification. To achieve the required results these techniques should be implemented globally. These proposed techniques are characterized as:

- **Afforestation:** Trees are efficient CO_2 absorber and planting the trees on global scale can contributes significantly in CO_2 reduction.
- **Bio-Energy with Carbon Capture and Sequestration:** In this technique bio-energy is generated from bio fuel and CO_2 emitted in this process is separately stored from environment.
- **Ambient Air Capture:** In this propose technique CO_2 can segregated from ambient air and stored separately.

- **Ocean Fertilization:** By increasing the phytoplankton growth in ocean atmospheric CO_2 concentration can be reduced.
- **Enhanced Weathering:** According to this technique various mineral can be released in the atmosphere where it will react with atmospheric CO_2 and results in some other product.
- **Ocean Alkalinity Enhancement:** Adding up the CO_2 absorbing rock in ocean for increased CO_2 absorbing power of ocean and this will reduce the acidity of ocean as CO_2 in not absorbing in ocean water.

International Efforts: Conference of Parties (COP) and Meeting of Parties (CMP)

To monitor the effort of different countries towards the mitigation of climate system, conference of the parties (COP) has been formed. COP assesses the contribution of countries by reviewing the national conferences and emission inventories submitted in COP. First COP was held in 1995 in Germany and after this it has been organized every year. President of COP are from one of the five UN recognized regions: Africa, Asia, Latin America and Caribbean, Europe and others on rotations. Under COP, countries are classified into three classes (i.e. Annex I, Annex II and Non-Annex I) in the view of their commitment towards GHG emission reduction.

Industrialize countries which were also the part of OECD (organization for Economic Co-operation and Development) in 1992 along with the countries part of Economies in Transition (EIT Parties), Russian Federation, Baltic States and European States, all together classified as parties under Annex I. Countries which were parties in Annex I and part of OECD were made parties in Annex II and these parties where not under EIT. Parties under Annex II are supposed to provide the financial and technical support to developing countries for the reduction in GHG emission and in developing the cleaner technologies. Most of the developing countries are the parties in Non-Annex I group.

In 1992 a summit, the United Nations Conference on environment and Development (UNCED), was held and as an outcome 'the United Nation Framework Convention on Climate Change (UNFCCC)' was form with an object stabilize greenhouse gas concentration in the atmosphere at safe level. Though UNFCCC was formed 1992 but it become functional in 1994 and first meeting of Parties (Conference of Parties: COP) was held in 1995 at Berlin. One of the most recognized COP meeting (i.e. COP3) was in held in Kyoto in 1997 and negotiation of this meeting is famous as Kyoto Protocol (KP). Most of the developed and central European countries agreed reduce the emission of GHG emission to below of 1990 level, between 2008 to 2012. Under Kyoto protocol, a milestone in the direction of climate protection, developed countries committed to stabilize the production of GHG and other countries also encouraged to do so. In KP, 37 countries including US and European countries aimed to reduce GHG emission in a specified time limit. In first commitment period (i.e. 2008 to 2012) a reduction of 5% from 1990 emission level was targeted to achieve. As developed countries were prime emitter of GHG and are responsible for present crisis, thus under KP, developed countries were bounded for large reduction in GHG. 55 countries including those which were responsible for most of the global GHG emission during nineties adopted the Kyoto Protocol which Russia asked more time to think on it.

The COP 8 was held in New Delhi in 2002 and notable commitment from this meeting was agreement of developed countries for technology transfer to developing countries in order to reduce the impact of climate change on developing countries, developed countries agreed for technology transfer in this COP. The first Meeting of Parties (CMP-I) or COP-11 was held in Montreal, Canada in 2005. In this meeting countries agreed to extend the Kyoto Protocol beyond 2012 to achieve GHG emission cutoff. In 2012, at COP18, an amendment to Kyoto Protocol had been applied with in second commitment period until 2020 because several countries i.e. Japan, Russia, New Zeal land, China, India and Brazil are not the subject to emission reduction under this protocol and these amendment are famous as Doha amendments. In 2012, in Doha, the Doha Amendment to Kyoto Protocol has been adopted and next commitment period is 2013 to 2020. Recent COP (i.e. COP20) occurred at on 2014, Lima, Peru and coming up COP21/CMP11 will be held at Paris, France. Regarding Lima meeting UN Secretary stated it as "The decisions adopted in Lima pave the way for the adoption of a universal and meaningful agreement in 2015".

After recognizing the severity of climate change global efforts have started and strengthened to reduce its impact. In these efforts OECD is forefront in making climate policies and implementation from last two decades. Global policy and its strict implementation of it is required by all countries in order to achieve the reduced GHG emission and reduced global warming. All countries should be forced to pay for their GHG emission and carbon taxed can be efficient strategy for preventing or reducing the GHG emission. This will encourage the countries to find alternative energy sources and develop new energy efficient and cleaner technologies.

National Plan: National Action Plan on Climate Change (NAPCC)

In current decade China, India and Brazil are the major GHG emitter countries and part of Non-Annex-I parties. Under this section we are discussing the India's plans and commitments for GHG emission reduction. In 2008 India's first action plan came into picture for GHG emission reduction. In this plan existing plans, future polices, mitigation plans and adaptation has been reviewed and discussed. The major plans have eight prime modules to make this plan functional and successful. The prescribed time limits for this project have been set to 2017.

- **National Solar Mission:** Solar energy is prime source of energy to the earth and acts as renewable energy source. Solar energy is widely used in developed countries as energy source along with conventional energy source. Thus under this plan solar energy has to be promoted in order to replace fossil fuel energy. Highlights of this plan are
    - Encourage use of solar energy in urban areas industrial and commercial areas.
    - Production of solar energy is still not up to the expectation thus increase the solar energy production is second major objective of this mission.
    - Efficient distribution system of thermally generated energy
    - Price of solar techniques are high as compared to traditional energies thus high research opportunities are in this field and research laboratories should establish for good research.

NATIONAL MISSION FOR ENHANCED ENERGY EFFICIENCY

Under this mission saving of 10000 MW energy was intended to save by year 2012. This was primarily based on Energy Conservation Act 2001 and theme essence of this mission can be summarized as

- Energy consumption should be reduced at industrial level and companies should have energy saving certificate,
- Reduced taxes on energy efficient techniques, and

- Promote energy conservation in various sectors as agricultural, building, municipal and also financially supporting the public-private partnership.
- **National Mission on Sustainable Habitat:** Energy efficient techniques should be used urban planning and governmental support and encouragement should be provided to promote this. Strategies for this can brief as
  - Existing energy efficient and conservation building scheme should be extended.
  - Waste management and recycling and power generation should be encouraged.
  - Use and availability of public transportation should be encouraged and increased.
  - Fuel efficient vehicles should be encouraged for transport and emission standards in usual vehicle should be implemented strictly for reduction in GHG emission from vehicular emission.
- **National Water Mission:** water crisis is going to serious impact of climate change and thus measures to reduce this starts from now by making efficient method for water saving and applying a check on wastage of water through penalty. Under this plan aim of 20% water saving efficiency is aimed to achieve.
- **National Mission for Sustaining the Himalayan Ecosystem:** Enhanced emission of black carbon has changed the Himalayan ecosystem and sustainability of this ecosystem is at risk. Shrink of the Himalayan glacier is well known and at same time topic of serious concern. To prevent the Himalayan ecosystem and glacier a collective effort at governmental and individual level should be promoted.
- **National Mission for a "Green India":** Aforementioned in this chapter the pros and cons of the deforestation which have increased owing to industrialization and urbanization. Urbanization have casted us heavily in terms of forest and thus under this mission a goal of achieving 33% forest area in the Indian territories have been intended.
- **National Mission for Sustainable Agriculture:** India is an agriculture based country but still this sector is unattended in term of weather related issues. Thus under this plan agricultural practices should be changed depending on situation demanded by climate change and agricultural sector should be made more secure and insured.
- **National Mission on Strategic Knowledge for Climate Change:** Though climate change is most burning issue in current days and efforts are made at governmental level but private sectors and individuals also should contribute for reducing the impact and prevent from increasing the causes for climate change. Collaboration and knowledge exchange schemes should be encouraged from institutes and governmental level in finding solution to overcome this problem. Intellectual efficiency climate modeling, institutional interaction and funding for research intensive should enhance.

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Section 9
Adaptive Capability

Chapter 22
Coastal Poverty, Resource-Dependent Livelihood, Climate Change, and Adaptation:
An Empirical Study in Indian Coastal Sunderbans

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ABSTRACT

Millions of people in Sunderbans generate their livelihood and sustenance through fishing, honey collection, fuel wood and timber. The paper attempts to examine the issues of coastal poverty, food security as well as livelihood insecurity and the adaptation options that help to the resilience of climate change. The paper is based on field survey conducted in the villages of Sunderans in 2011. The study revealed that fishing and crab collection, honey collection are the important sources of livelihood. The fishing resources have been declining which leads to the insecurity of livelihoods of the fishing communities. The study has identified the key adaptations like dependency of money lenders, fishing and crab collection, formation of Self Help Groups, livestock rearing and migration. This paper has important policy implications for poverty, livelihood vulnerability and migration.

1. INTRODUCTION

In India 700 million rural populations directly depend on climate-sensitive sectors like agriculture, forest and fisheries, and natural resources for livelihood generation. Fisheries-related activities provide important sources of livelihoods for nearly 7 million people in India (Government of India, 2000). Climate change is considered to be one of the major threats to sustainable development because of its effects on health, infrastructure, agriculture and food security, and forest ecosystems (IPCC, 2007 a). Moreover, climate change deteriorates living conditions in many parts of the world including India. People are severely affected by environment degradation or restrictions imposed on the access to it. As a result of this dependency, the impact of climate change

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threatens the livelihoods, food intake and health of the poor people (Smith and Troni, 2004). A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain its capabilities and assets both now and in the future, while not undermining the natural resource base. (Carney, 1998b).

Poverty in coastal areas is more than that of non-coastal areas. Based on the definition of poverty as the inability to secure a minimal standard of living (National Institute of Rural Development – NIRD, 1998: 5), the majority of coastal fishers can be defined as poor. Climate change affects the environmental and socio-economic drivers of food insecurity, as its impacts are largely affected by poverty and inequality. Over time, climate change will affect all four components of food security: availability, access, utilization and stability (FAO, 2009; Vermeulen *et al*., 2012). Changing climatic conditions will affect crop growth and livestock performance, the availability of water, fisheries and aquaculture yields and the functioning of ecosystem services in all regions (Foresight, 2011). Saltwater intrusion threatens some of the major food-producing regions in the world that are located in mega-deltas, where also much of the world's population lives (Beddington *et al*., 2012).

There exists extensive literature on poverty, its definition, measurement, and alternative conceptual approaches to it in development and environmental economics (Sen, 1999; Alkire 2002, Dasgupta 2001; Nussbaum and Sen (1993) and Qizilbash 1996). Sen provides "Capability Approach" to poverty and human well-being which makes a distinction between well-being, agency achievement and freedom. Dasgupta's (2001) version of well-being is more operational and includes liberties, income, health and education. He suggests focusing attention on the sustainability of well-being and talks in terms of need for comprehensive measurement of wealth.

The analysis of poverty is highly related to the analysis of food security. Gulati (2006) expressed food security at national to household level as it is more a matter of economic access than that of physical availability in developing and developed countries. In the views of Mishra (1998) food security would mean ensuring all people to have physical and economic access to the basic food they need to work and function normally.

George (1999) while analyzing food security situation in India found that economic access to food could be achieved through a mix of employment and income policies for farm sector.

While analyzing food security and nutrition: Vision 2020, Reddy (2004) said that while India achieved success in combating transient food insecurity caused by droughts or floods, it miserably failed to make much dent in chronic food insecurity as reflected in the low energy intake and high incidence of malnutrition.

Swaminathan (2000) has equated food security with livelihood security at the levels of each household and all members within and involves ensuring both physical and economic access to balanced diet, safe drinking water, environment sanitation, primary education and basic health care.

A better understanding of the complex nature of livelihoods has derived largely from work conducted in research into poverty (Sen, 1981; Narayan *et al.*, 2000). Income measures and ownership of assets like land which failed to capture many key issues of poverty like marginalization and vulnerability. IFAD (2002) considers coastal areas in Asia are prone to poverty and coastal fishing households are regarded as being amongst the poorest of the poor, largely on the basis of their dependence on an open-access resource where competition is high and increasing. The ability of the rural poor to sustain their livelihoods is believed to be constrained due to adverse environmental conditions – high ecological vulnerability and low resource productivity – and limited access to land and other natural resources (UNCHS, 1996; World Bank, 2002). In a pioneering study in the Indian context, Jodha (1986) found that there is a negative relationship between the total income of the household and the share of total environmental income in it. This reflects that poorer households are more resource dependent than the rich. His study also showed that income from the commons comprising between 9 and 26 percent of the total incomes of poor households and between 1 and 4 percent of the incomes of rich households. According to Jodha's (1990) estimates, the inclusion of CPR income in total household incomes reduces the extent of rural income inequalities as indicated by lower values of the Gini coefficient.

There is considerable research in the area of vulnerability to climate change (Adger 2006), much of it focused on conceptualizations of vulnerability and its relationship to adaptation (Cutter et al., (2009). The other issues of climate change are sustainable livelihoods and vulnerability to poverty, and the vulnerability and resilience of social-ecological systems. Many of the studies are simple conceptual diagrams useful for framing the issue of vulnerability to climate change at macro (global) scales (Füssel 2007; Heltberg et al. 2009; Ionescu et al. 2009). Others focus explicitly on adaptation (Kelly and Adger 2000; Smit et al. 2000; Brooks 2003; Downing and Patwardhan 2004; Adger et al. 2005; Brooks et al. 2005; Füssell and Klein 2006; Füssell 2007; Smit and Wandel 2006; Yamin et al. 2005).

However, most of the above studies are unable to provide critical insights in terms of the adaptation strategies at the micro or household level. Much of the works on adaptation are focusing on the identification of potential impacts of future climate change with the help of General Circulation Models (GCMs). But the GCMs are extremely limited in analyzing about regional impacts of climate change and did not focus on local level adaptation.

Given this background, the objectives of the paper set the following;

Firstly, the paper attempts to examine poverty in the Bay of Bengal as well as also examines poverty and food security in coastal Sunderbans in West Bengal, India. Secondly, the paper attempts to examine the impact of climate change on livelihood insecurity of coastal people in Sunderbans with the help of factor analysis. Thirdly, the paper tries to identify the possible adaptation options to climate change. Lastly, the paper examines the role of the Government in developmental policy.

2. MATERIALS AND METHODS

2.1. Study Area

The world's largest mangrove forest, the Sunderbans, is located at the apex of the Bay of Bengal and is presently spread over an area of 25,000 sq. km. in India and Bangladesh, out of which the Indian part consists of 9,630 sq.km. (Chopra et al, 2006). The Sunderban Reserve Forest in Bangladesh and India comprises approximately 60 percent and 40 percent of the total area respectively and comprises delta of three great rivers the Ganges, Brahmaputra and Meghna along the Bay of Bengal. The entire Sunderbans region in India was declared as Global Biosphere Reserve by UNESCO in December 2001.

The Indian Sundarban comprises 19 community development blocks- 13 under South 24 Parganas and 6 under North 24 Parganas district of West Bengal with a total population of 4.1 million. At least 5 of the 13 Sundarban blocks are entirely or mostly constituted by islands which do not have a direct road link with the mainland. These are Gosaba, Basanti, Kultali, Patharpratima and Sagar. 44% of population belongs to schedule caste and tribe, 85% are living on agriculture, of which 90% are landless agricultural labourers and marginal farmers. Frequent climatic insult is a regular feature like cyclonic storm. Tidal waves and flooding are the causes of recurrent damage of life, crops and property every year in Sunderbans.

2.2. Method of Data Collection

Data were collected by conducting field survey in the Coastal Sunderbans, West Bengal in India. The field work combined interviews and discussions with the local people and interviews with local experts and school teachers and other knowledgeable elders in the village. This study was conducted in two villages- of Gossaba block in coastal Sunderban, West Bengal, namely Jamespur and Chargheri in 2011. The study selects 30% households randomly from each village. Total number of sample households in coastal Sunderbans was 202. In the village of Jamespur we have 104 households and in the village of Chargheri we have 98 households selected on the basis of random sampling without replacement. A total of 202 structured household interviews were conducted.

2.3. Data Collection

Data on socio-economic variables, like age, sex, education, land holdings, livelihood, and adaptation measures like migration, fishing & crab collection; self-help groups, livestock rearing etc. have been collected from the field survey. The socio-economic indicators of two villages are presented in the Appendix A.

2.4. Analytical Methods

The paper has analyzed major dimension of livelihood insecurity using Factor analysis.

2.4.1. A Factor Analysis

Factor analysis (FA) model assumes that the variances are decomposed into that accounted for by common and unique factors.

The model is given by:

$$X_1 = a_{11} F_1 + a_{12} F_2 + \text{--------} + a_{1m} F_m + e_1 \quad (1)$$

$$X_2 = a_{21} F_1 + a_{22} F_2 + \text{--------} + a_{2m} F_m + e_2$$

$$X_3 = a_{31} F_1 + a_{32} F_2 + \text{--------} + a_{3m} F_m + e_3$$

$$X_Q = a_{Q1} F_1 + a_{Q2} F_2 + \text{--------} + a_{Qm} F_m + e_Q$$

where X_i = (i= 1, 2, 3, ------G) represents the original variables but standardized with zero mean and unit variance; a_{i1}, a_{i2}, ---- a_{im} are the factor loadings related to the variable X_i F_1, F_2, ------F_m are m uncorrelated common factors, each with zero mean and unit variance and e_I are the Q specific factors supposed independently and identically distributed with zero mean.

Principal component analysis (PCA) method is utilized to bring few factors that construct various major dimensions of livelihood insecurity. Following the Kaiser criterion, i.e. only factors/components having Eigen value >1, have been taken into the analysis.

3. RESULTS AND DISCUSSIONS

3.1. Results on poverty and food security

Number of people below the poverty line across the blocks of Sunderbans is presented in Table 1. The average poverty ratio is 43.51% which is much higher than the state average (about 30%). The poverty ration is found to be highest in the Basanti block (64.89%) followed by Sandeshkhali (60%) in Sunderbans (Table 1).

Table 1. Poverty in Coastal Sundarbans, West Bengal, India

Name of the Blocks	Poverty Ratio (% hhs Below Poverty Level)
South 24 Parganas	
Canning 1	31.05
Canning 2	50.32
Jaynagar 1	39.57
Jaynagar 2	42.6
Kultali	46.36
Basanti	64.89
Gosaba	38.03
Mathurapur I	34.43
Mathurapur II	39.59
Kakdwip	34.91
Sagar	44.46
Namkhana	48.17
Patharpratima	49.13
Average	43.51
Rest of South 24 Parganas	24.43

Source: Anon 2009, *District Human Development Report, North 24 Parganas*, Development and Planning Department, Government of West Bengal; Anon 2009, *District Human Development Report, South 24 Parganas*, Development and Planning Department, Government of West Bengal

Table 2. Food security in the Block of South 24 Parganas

Name of the Blocks of South 24 Parganas	Less than One or One Square Meal per Day	No Food Shortage
Canning 1	13.73	17.63
Canning 2	20.77	7.6
Jaynagar 1	19.98	18.87
Jaynagar 2	18.97	10.8
Kultali	15.21	11.08
Basanti	36.93	6.54
Gosaba	15.42	17.52
Mathurapur I	16.96	10.41
Mathurapur II	20.4	13.69
Kakdwip	16.35	18.15
Sagar	28.3	8.97
Namkhana	22.55	9.91
Patharpratima	27.37	11.06
Average	20.99	12.47

Source: Anon 2009, *District Human Development Report, South 24 Parganas*, Development and Planning Department, Government of West Bengal

Another indicator of poverty is the state of food security. Food security across different blocks of Sunderbans is shown in Table 2. Out of 13 blocks of the South 24 Parganas, only 12.47 per cent people face no shortage of food implying 87 per cent have no food security. About 21 per cent of the population (more than one person in every five) does not get food even once a day on a regular basis which is evident from Table 2. Comparing to 13 blocks the number of people having one square meal per day is found to be highest (37%) in Basanti block in Sunderbans (Table 2*)*.

The issue of food security in the Bay of Bengal region is also closely related to the issue of poverty. In the south Asian region particularly in India and Bangladesh, the causes for the failure of food security are not associated with the failure of food supply rather to failure in access to food. This is also true for those livelihoods depend on coastal and marine resources. Failures of those resources either they are degraded or over exploited and limited access to those resources.

The FAO estimates (FAO, 2002) that there are approximately 19 million people involved in fisheries in Asia who are "income poor" (see Table 3). This is based on estimates of those living below the overall World Bank poverty line of US1$ per day and assumes that the proportions of the poor in fishing communities is the same as in the rest of the population at large. In many parts of the region, fishers and fishing communities are under the depth of poverty in relation to other groups in rural areas.

Turning to some standard of living indicators, from Table 4, it is seen that the island blocks are lagging behind the rest of Sundarban blocks. This

Table 3. Poverty in small-scale fisheries communities in Asia

% of Population on < US$1 per Day	25.6%
Inland	514,023
Marine coastal	95,837
Marine other	551,133
Unspecified	3,660,428
Total nos. of fishers	4,821,421
Number of related income-poor jobs	14,464,262
Total income-poor in small-scale fisheries	19,285,683

Source: FAO, 2002

Table presents living status using five indicators which are considered as basic requirements for human living.

3.2. Results on Impact of Climate Change on Livelihood Security

The results of field study revealed that most of the households in both villages comprise landless, marginal and small farmers. Households have been categorized as single occupation households (who are generally engaged in either only agriculture or only wage labour or only fishing & crabs), double occupation households (who are engaged in either agriculture & fishing or Agriculture & wage labour or fishing & wage labour simultaneously) and more than double occupation households (who are engaged in agriculture, fishing and wage labour). Larger percentage of households is engaged in more than double occupation (39.5% households in the village of Jamspur and 72.5% households in the village of Chargheri), shown in Table 5.

The study has identified five sources of livelihoods such as agriculture, wage labour, honey collection, fishing & crab collection and van puller. These are presented in Table 6. It is observed from Table 6 that the households' first preference is fishing and crabs collection (72% in the village of

Table 4. Intra-regional disparity in some indicators of standard of living

Standard of Living Indicators	Island-Blocks [1] around Forest Boundary	Other Sundarban Blocks
% of localities that are fully covered by provision of safe drinking water	38.8	41.4
% of households that are homeless	5.3	3.8
% of households that live in huts with only one room	71.7	60.4
% of households having less than two garments per member	12.3	9.3
% of households having two to four garments per member, but without any winter garment	35.6	30.6

Source: Rural Household Survey 2005, Office of the District Magistrate, South 24 Parganas

Note [1] Island blocks consist of Gasaba, Basanti, Kultali, Patherpratima and Sagar.

Jamespur and 60% in the village of Chargheri) .The second source of livelihood is wage labour(35% in the village of Jamespur and 55% in the village of Chargheri) and agriculture is their third source of livelihoods (14% in the village of Jamespur and 10% in the village of Chargheri). The result shows that the first source of livelihoods is fishing and crabs collection.

The result of climate change impact on livelihoods is presented in Table 7. Households were asked to identify the impacts of climate change on their livelihoods like the amount of fish collection decreased, decreased in fishing days, deceased in fish catch per go, decreased in the amount of honey collection, decreased in honey collecting days and decreased in amount of crab collection. It is revealed that the fishing and crab collection have been decreasing. The study also showed

Table 5. Distribution of occupation

Name of the Villages	Household		
Jamespur	Single occupation	Only agriculture	1(0.9)
		Only wage labor	4(3.8)
		Only fishing	12(11.5)
	Double occupation	Agriculture & fishing	13(12.5)
		Agriculture & wage labor	6(5.8)
		Fishing & wage labor	41(39.5)
	More than double occupation	Agriculture, fishing & wage labor	23(22.2)
		Agriculture, fishing &honey	4(3.8)
	All		104(100)
Chagheri	Single occupation	Only agriculture	-
		Only wage labor	3(3)
		Only fishing	1(1)
	Double occupation	Agriculture & fishing	-
		Agriculture & wage labor	5(5.1)
		Fishing & wage	71(72.5)
	More than double occupation	Agriculture, fishing & wage labor	18(18.4)
		Agriculture, fishing &honey	-
	All		98(100)

Note: Figures in the parentheses represent percentage

Table 6. Preferences of livelihood of the households in the two villages

	Sources of Livelihood	Agriculture	Wage Labour	Honey Collection	Fishing & Crabs	Van Puller
Jamespur	First source	3(2.9)	29(27.9)	0(0)	75(72.2)	1(.95)
	Second source	24(23.1)	37(35.6)	9(7.7)	12(11.5)	2(1.9)
	Third source	15(14.4)	8(7.7)	1(0.95)	2(1.9)	0(0)
Chargheri	First source	2(2.04)	36(36.7)	1(1)	59(60.2)	0(00
	Second source	10(10.2)	54(55.1)	1(1)	29(29.6)	0(0)
	Third source	10(10.2)	5(5.1)	0(0)	1(10)	0(0)

Note**:** Figures in the parentheses represent percentage
Source: Field Survey

Table 7. Impact of Climate change on Livelihood in Coastal areas of West Bengal

	Responses	Fish Collection Decreasing (%)	Decrease Fishing Days (%)	Decrease Fish Catch per Go (%)	Honey Collection Decreasing (%)	Decrease Honey Collecting Days (%)	Crabs Collection Decreasing (%)
Jamespur	Yes	99(95.2)	90(86.5)	88(84.6)	42(40.4)	41(39.4)	98(94.3)
	No	0(0)	8(7.7)	7(6.7)	20(19.2)	14(13.5)	2(1.9)
	Don't know	5(4.8)	6(5.8)	9(8.7)	42(40.4)	49(47.1)	4(3.8)
	All	104(100)	104(100)	104(100)	104(100)	104(100)	104(100)
Chargheri	Yes	96(98)**	93(95)	89(90.8)	9(9.1)	9(9.2)	86(87.8)
	No	1(1)	4(4)	4(4.2)	23(23.6)	21(22.4)	2(2)
	Don't know	1(1)	1(1)	5(5)	66(67.3)	67(68.4)	10(10.2)
	All	98(100)	98(100)	98(100)	98(100)	98(100)	98(100)

Note: Figures in the parentheses represent percentage
Source: Field Survey

that the amount of honey collection has also been decreasing (40% in the village of Jamespur and 9% in the village of Chargheri).

3.3. Results on Insecurity of Livelihoods by Factor Analysis

For reduction of a number of variables related to the livelihood security into a meaningful and manageable category all eight questions like amount of fish collection decreasing, decrease in fishing days, decreasing fish collection per go, amount of honey collection decreasing, decreasing honey collection days, decrease in crab collection, decrease in min (shrimp) collection and decrease in density of mangrove forests were taken into analysis for the factor analysis.

The component wise Eigen values are shown in Table 8. Factor- wise load factors of variables are presented in Table 9.

The first factor could be termed as "amount of fishing collection, decreasing fishing days and decreasing fish collection per go", which constitutes 3 variables that explain 31.13 percent of variances. The second factor could be summarized as "amount of honey collection decreasing and decreasing honey collection days" which constitutes 2 variables that explains 23.79 percent of variances.

It is to be noted here that as the value of determinant of correlation matrix was found greater than 0, the Kaiser –Meyer-Olkin value of sampling adequacy was 0.84, the Bartlett's test of sphericity was significant at $p<0.0001$ and the average communality was >0.500 the factor analysis is considered statistically valid (Field 2005; George and Mallery 2006, Hair et al. 2006).

Table 8. Component wise Eigen values

Component	Initial Eigenvalues
1	2.491
2	1.903
3	0.925
4	0.893
5	0.845
6	0.491
7	0.257
8	0.196

Table 9. Roated factor loading matrix of factor variable which constitutes the livelihood security[1]

Variable	Factor	
	1	2
Amount of fishing collection decreasing	0.89	-0.002
Decrease in fishing days	0.86	-0.006
Decreasing fish collection per go	0.74	-0.001
Amount of honey collection decreasing	0.003	0.89
Decrease in honey collection days	0.004	0.92
Decreasing in crab collection	0.38	0.13
Decreasing in min collection	0.42	0.18
Density of mangrove forest decreasing	0.26	-0.43
Variance (%)	31.13	23.79
Cummulative variance (%)	31.13	54.92

Note 1: Extraction method: Principal component Analysis; rotation method: Varimax with Kaiser. Normalization (Rotation converged in 14 iterations).

3.4. Results on Adaptation

The possible adaptation options reported by the households were distress migration, formation of self Help Groups (SHGs) in the micro finance program, livestock rearing, fishing and crab collection, diversifying their livelihood into daily wage labour, accessing loan facility (Table 10).

Households take loan in times of urgent needs the money lenders. These are used for house repairing and small business. It is observed from Table 10 that more than 80% households borrowed loan from money lenders.

Livestock rearing is one of the important adaptations for income generation. 78% households in the village of Jamespur and 70% households in the village of Chargheri reported that they rear livestock asset like cow, goat, hen, sheep and pigs for additional income generation (Table 10).

Table 10. Adaptation options of the households

Strategy	Jamespur (Yes)	Chargheri (Yes)
Accessibility of loan from:		
1. Banks	12(11.5)	16(16.3)
2. Money lenders	91((87.5)	81(82)
Livestock rearing	82(78.8)	69(70)
SHG	81(77.9)	89(90)
Migration	76(73)	84(85)
Fishing & crabs collection	89(85.5)	89(90)
Diversification into wage labour from agriculture and forestry	80(76.9)	96(98)

Figures in the parentheses represent percentage
Source; Field survey

Formation of SHGs is also one of the effective methods of climate risk reduction. Increased income helps them to manage climatic risks (77% households in the village of Jamespur and 90% households in the village of Chargheri formed SHG (Table 10). SHGs through microfinance are a tool that can reduce the vulnerability of the poor and the possibility of linking this tool to climate change adaptation is of considerable importance (Hammill et.al. 2008). The Self Employed Women's Association (SEWA) in India offers housing loans to repair or replace roofs, reinforce walls, or rebuild houses which are used to reduce vulnerability to extreme events such as floods, droughts and storms (Pantoja, 2002). In addition, microfinance service has the potential to help the world's poor and most vulnerable population adapt to climate change by providing them with a means of accumulating and managing the assets and capabilities (Swift 1989; Ellis 2000).

Salinity water present in the agricultural land due to sea level rise causes to damage agricultural crops. This leads to shortage of food. As food stock continues to, migration continues to rise. In both the villages more than 70% households migrate to the urban areas. Migration by the poor as a response to natural calamities and other shocks have been documented (Murthy, 1991; Mukherjee 2001).

Fishing and crab collection is one of the income generating activities for livelihood. In the study area there is conversion from fishing to wage labour. The main causes behind this conversion include a decrease in both the fish stocks, which are aggravated by climatic changes in rain and temperature and increased cyclone activity. In the region one of the most common adaptations is a diversification of daily wage (76% in the village of Jamespur and 98% in the village of Chargheri reported that they adapting to daily wage labour work for their livelihood)(Table 10). The causes of diversification in this region are lower amount of fish and crabs collection and the problems of getting boat licenses etc.

4. CONCLUSION AND GOVERNMENT POLICY

From the above analysis the following conclusions are emerged;

Firstly, the poverty is acute in coastal Indian Sunderbans. Secondly, food insecurity is present in Sunderbans. In the 13 Sundarban blocks of the South 24 Parganas, only about 12.47 per cent people face no shortage of food and 87 per cent have no food security. Close to almost 21 per cent of the population (more than one person in every five) do not get food even once a day on a regular basis. In block like Basanti, this figure is as high as 37 per cent (or one in every three).

Thirdly, most of the households in both the villages comprise landless, marginal and small farmers and fishing, crab collection, honey collection are the important sources of livelihood. The livelihood impact of climate change has been examined by factor analysis. From this factor analysis it has been revealed that first factor is termed as "amount of decreasing fishing collection, decreasing fishing days and decreasing fish collection per go", which constitutes three variables that explain 31.13 percent of variances. The second factor is summarized as "amount of honey collection decreasing and decreasing honey collection days" which constitutes two variables that explains 23.79 percent of variances. This result implies that the livelihoods of the fishing communities are insecure.

Fourthly, the paper has identified the possible adaptation options of the households like the formation of self-help groups, migration, livestock rearing, borrowing of loans from money lenders, fishing and crab collection and diversification into wage labour from agriculture and fishing.

Developmental efforts by the Government of India help to build adaptive capacity through two levels of interventions. First, climate specific interventions campaigning awareness about available flood, cyclone, better access to medium / long range weather forecasts, and possibly early warning networks. Secondly, to building up broader capacity through education, access to agricultural credit, health care, and infrastructure, etc. For developing countries like India, adaptation requires assisting the vulnerable population during adverse climate conditions and empowering them to cope with climate risks in the long-run for better living. The Government of India implements a series of central and centrally sponsored schemes under different ministries and departments for achieving social and economic development. At present, while none of the schemes is explicitly referred to as Adaptation schemes; many contain elements (objectives and targets) that clearly relate to risks from climate variability. A recent initiative by the Department of International Development (DFID) and the World Bank in India seeks to identify how to integrate adaptation and risk reduction into their portfolio of programs.

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APPENDIX

Table 11. Socioeconomic indicator in Coastal area of Sunderban

	Jamespur	Chargheri
Caste		
General	0(0)	5(5.1)
Schedule caste	104(100)	93(94.9)
Schedule tribe	-	-
Gender		
Male	98(94.2)	96(98)
Female	6(5.8)	2(2)
Age		
≤30	19(18.3)	13(13.3)
31-40	27(26.3)	38(38.8)
41-50	24(23)	24(24.5)
51-60	18(17)	11(11.2)
Above60	16(15.4)	12(12.2)
Education		
Upto Primary (in 4-year)	27(26)	19(19.3)
Upto secondary (5-10 year)	28(27)	27 (27.7)
Higher secondary(10-12 year)	3(2.8)	1(1)
College(above 12 year)	0(0)	1(1)
Not through formal education	5(4.8)	2(2)
Illiterate	41(39.4)	48(49)
Family Size	4.4	4.3
Male	175	146
Female	152	140
Children	131	132
Land Holdings (in Acres)		
Landless	58(56)	77(78.6)
≤1	42(40.2)	19(19.4)
1-2	3(2.9)	2(2)
Above 2	1(0.9)	-

Note: Figures in the parentheses represent percentage
Source: Field Survey

Chapter 23
Climate Change and Adaptation through the Lens of Capability Approach:
A Case Study from Darjeeling, Eastern Himalaya

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ABSTRACT

Climate Change impacts would disproportionately have larger impacts on the developing countries. Both government and development agencies have initiated various adaptation strategies in the developing countries to enhance the adaptation of the local communities. Various policies and programmes have been designed keeping in mind the impact of climate change. This study was conducted in Darjeeling district of West Bengal, India, to see the benefits of such policies and programmes. Focus group discussion with community members were held in the study area. Based on the fieldwork it was seen that most of the intervention made in the study area focused on income, resources, and assets. It has failed to benefits the people due to variation in the capability among various section of the society. Various projects related to health, education, housing, and livelihood, have been implemented in the study region. However, due to lack of conversion factors in the form of gender inequality, discriminatory practices, transparency among others have come as a hindrance in the successful implementation of the projects. Hence, such project-based approach to enhance community's adaptation to climate risk, in the end fails to show benefits as it fails to expand community's capabilities and real freedom, due to the project's pre-defined aims. It is important to understand community's as agent of change rather than merely beneficiaries of adaptation projects. This study therefore recommends that to enhance community's adaptation to climate change, the interventions should be such that it enlarges the range of people's choices so that when climate disaster strikes them they will have a set of opportunities.

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INTRODUCTION

Climate change is gaining importance as scientific and socio-economic studies have brought forth substantial evidences (American Meteorological Society, 2012; Norris et al. 2008; Agrawal& Perrin, 2008; Paavola, 2008; IPCC, 2007; UNFCCC, 2007; Adger& Kelly, 1999). The impacts of climate change are more likely to be adverse in developing countries due to their high dependence on climate sensitive livelihoods like rain-fed agriculture, and forestry (Moorhead, 2009). Climate change policies are crucial for enhancing adaptive capacity of an individual. Institution plays an important role in community's adaptation to climate change (Berman, Quinn, & Paavola, 2011). The human development report of 2007-08 also declared that climate change has limited the choice of an individual and would further erode 'human freedoms' (UNDP, 2007/08). Here, human freedoms refer to the capabilities, which depend upon the choices and opportunities available to him/her (Sen, 1999). Capabilities enable individual to chose a particular option (like resource, assets, opportunities etc) and convert it into useful functioning. Climate change by eroding human freedoms reduces the choices and opportunities available to an individual. Therefore, it is important to internalize the linkage between 'capabilities' and 'adaptive capacity' to withstand the impacts of climate change in the context of developing countries.

Various researchers have established that larger burden of climate change disproportionately falls in the developing countries (Agrawal& Perrin, 2008; Norris et. al 2008; Paavola, 2008; UNFCCC, 2007; Adger& Kelly, 1999). Further, poor people in developing countries tend to be more vulnerable due to limited opportunities and choices, limited land holding size, and lack of access to market among other factors. Within the members of poor community, women are more vulnerable to the impacts of climate change due to lesser economic, political, and social opportunities in the society (Habtezion, 2011). Women are mostly responsible for activities like fetching of water, fuel wood, fodders, and other agriculture activities. Any changes in the climate would adversely affects the sources of water, fuel wood, fodders, and agriculture thereby increasing the workload of the women. Due to various cultural and social norms, unequal decision-making process, women are more likely to be affected by the impact of climate change.

Taking into consideration the aspects of climate change and its variation, this study makes an attempt to see the following research questions in Darjeeling districts of West Bengal.

- What are the various interventions made in the study region to adapt to climate change?
- Do social norms and customs limit community's ability to participate in and benefit from these interventions?

The discussions are based on extensive and critical review of literature on adaptive capacity and capability approach. It is organized into six sections; the first section discusses briefly about the relevance of capability in enhancing adaptive capacity to climate change. The second section is an overview of the linkages of adaptive capacity and capability approach. Section three discusses the methodology used in the study. Section four and fifth discusses the study area and results of the study. Finally section sixth concludes the study.

ADAPTIVE CAPACITY AND CAPABILITY APPROACH: THE LINKAGES

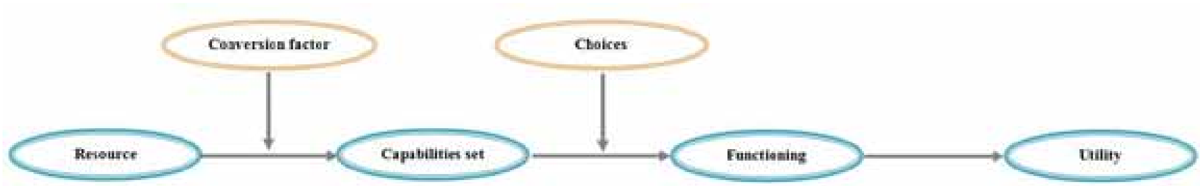
Climate change along with its environmental effects may come as a hindrance to the process of development if not addressed properly (EU, 2006). Therefore, development policy needs to be planned keeping in mind the importance of building adaptation to climate change. It should be designed to enhance adaptive capacity of the poor and marginalized section of the societies, as they are highly vulnerable due to lack of social, economic, and political opportunities. The concept of adaptive capacity was originally defined in biology to mean the ability to become adapted to certain range of environmental changes (Gallopin, 2006). In the recent time, the term "adaptive capacity" has been extensively used in the climate change research. In the context of climate change, adaptive capacity can be defined as the ability of the system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences while adaptation is defined as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects (IPCC 2001). Similarly, Adger & Vincent (2005, p. 402) describe adaptive capacity as the domain "within which adaptation decisions are feasible." Adaptive capacity of community or individual varies across and among different countries; different sections of population, among social groups, from community to community and within individuals. It depends upon various socio-economic and political factors like education, health, farm and non-farm assets, access to water and sanitation, gender equality, access to financial, technological and information, resources, access to government schemes, political participation among others. Various adaptive capacity frameworks have been developed to enhance the adaptive capacity of an individual or community. They vary in the scale of analysis and in terms of indicators, which reflects the adaptive capacity of an individual and community. The scale of analysis is either national or local level. The frameworks assess adaptive capacity through indicators like management; economic wealth; access to financial services; technology and information; resources; education; health; equity etc (IPCC 2001; Brooks et al. 2005). However, there are no general agreements among researchers on the indicators of adaptive capacity (Adger et al. 2004).

Development agencies like NGOs, research institutes etc have been working closely with communities to foster adaptation to climate change. A study conducted by the Oxfam, India shows that government intervention have been inadequate in sectors like food security, health, housing, education which are crucial for adaptation to climate change (Ganguly & Panda, 2010). It also stated that adaptation policies across the counties including India tend to focus on the short-term gains instead of long term benefits. Dixit, et al. (2012) and Jones, Ludi and Levine (2010), as a part of the African Climate Change Resilience Alliance Programme at the Overseas Development Institute (ODI), have developed framework to analyze adaptive capacity at national and local level, respectively. The national level framework developed by Dixit, et al. (2012), emphasized on the importance of institutional arrangements to build adaptive capacity. For instance, institutional functions such as assessment, prioritization, coordination, information managements, and climate risk managements are emphasized to build adaptive capacity at national level. In contrast, Jones, et al. (2010) developed a framework to assess adaptive capacity at local level. It focuses on assets, knowledge and information, innovation and flexible and forward thinking-decision making and governance, entitlements in addition to institutions. The framework incorporates both intangible and tangible (capitals and resource based) components. Williamson et al. (2012) proposed communities' adaptive capacity approach. The approach assumes that access to and ownership of resource and assets enhances a communities' general capacity to respond to sudden impacts. The enhanced capacity contributes to long-term sustainability of communities. However, although changes in the institutional arrangements are important, but voice of the communities in the decision-making process plays a crucial role in effectiveness of these institutions. Vincent's (2007) framework looks at the household adaptive capacity through an index comprising five indicators. These are economic wellbeing and stability, demographic structure, interconnectivity in higher-level processes, natural resource dependency, and housing quality. Cross-household comparison can be carried out considering these five indicators of adaptive capacity.

Recently, Governments across developing countries have been taking initiatives to fight the impacts of climate change by taking measures to enhance community's capacity to adapt (United Republic of Tanzania, 2012; Bwalya, 2010; Government of India, 2008). In India, Government of India has introduced national action plan on climate change (NAPCC) in the year 2008 with an aim to create awareness among various officials, agencies, industries, and communities (Government of India, 2008). These action plan aims to provide adaptation strategies among the vulnerable section of the society and aims for a sustainable development of the society. The main principles of the NAPCC are protecting the poor and vulnerable, sustainability, management, appropriate technology, innovation, effective implementation, and international cooperation (Government of India, 2008). However, it is likely to fail as it does not address the needs and challenges of the small and marginal farmers who are most likely to be affected by climate change (Byravan & Rajan, 2012). Apart from the NAPCC, the Government of India has implemented various rural development projects which directly or indirectly aim to enhance the adaptive capacity. These projects like the Mahatma Gandhi Nation Rural Employment Guaranteed Act (MGNREGA), Indira Awaas Yojna (IAY), food security schemes etc are mostly resource based. However, long-term adaptation measures needs to be undertaken to withstand the impact of climate change.

Most of the adaptive capacity frameworks fail to focus on capability aspects of the people. The projects which are externally supported usually aims in distribution of material resources (Castillo, 2014). Projects like water resources development, employment generation, housing, sanitation, connectivity, health etc, have been implemented with the aim to enhance adaptive capacity (American Meteorological Society, 2012; Jones et al. 2010; Cohen, 2009; Scoones, 1998). These projects are designed with an aim that enhancement of the availability of resources, assets, income would directly build adaptive capacity among individuals. Although income, resources and assets based approach are important, it is not sufficient to build adaptive capacity among individuals. The problem with such approaches is that they focus on short timescales and tend to neglect the longer- term perspective. Jones et al. (2010) pointed out that asset based indicators typically rely on aggregate proxy data and fail to capture the processes, and contextual and intangible factors like flexibility, innovations and redundancy which influence adaptive capacity. Similarly, Lindsey (2011) suggested that resources and assets do not give sufficient recognition to the processes and functions, which are important in building adaptive capacity. The distribution of income, resources and assets aims to provide subsidies and direct benefits to the poor (Basu, 2013). Barua et al. (2013) suggests that resources and assets distributed to enhance the adaptive capacity of the communities are short-term measures, thereby emphasized the importance of long-term measures like improvement in education, healthcare, livelihood opportunities, and access to market to build adaptive capacity. In fact, policies which focus only on the income, assets, and resources, will make the people more dependent, restricting their independence and empowerment. Instead, focus should be given on people's capacity to convert resources into productive assets rather than just on the income,

Figure 1. Conceptual framework of capability approach
(Alkire, 2003)



resources and assets. This is where capability approach can play a significant role in enhancing people's capacity to adapt.

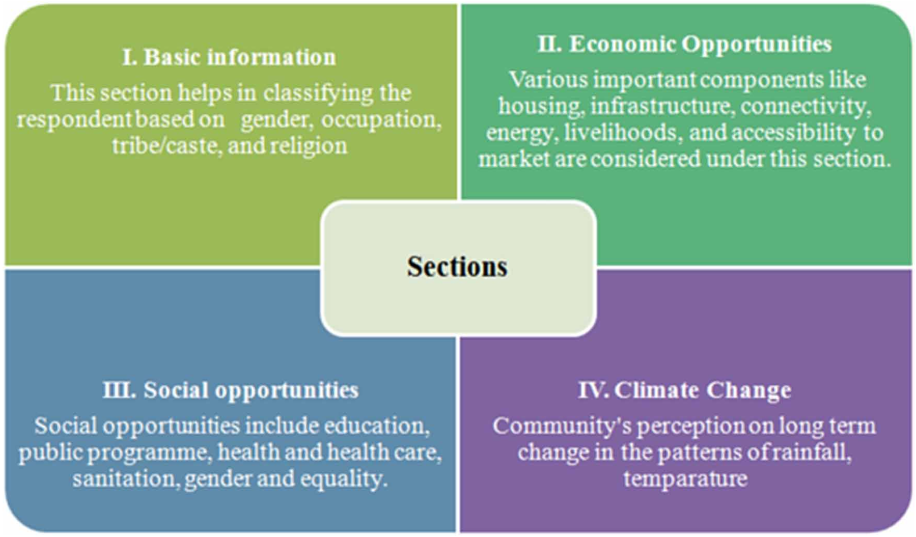
The capability based development policies would therefore facilitate in designing long-term intervention for enhancing the adaptive capacity of individuals and communities to climate change.

The concept of capability approach is based on four key concepts: resources, capabilities, functioning and utility (Verd & López, 2011; Alkire, 2003) (Figure1). The capability approach believes that although resources are equally distributed among different sections of population, utility of these resources will vary depending upon the capability of the particular individuals or communities (Sen, 1999). The capability approach argues that utility of a particular resource depends on various conversion factors such as social, physical and an environmental factor, which creates a sets of capabilities to use the resources (Robeyns, 2003). Capability sets are the various opportunities and choices available to a particular individual. Functionings are the conversion of these freedoms and opportunities into beings and doings. Choices are made from the capability sets based on the desired functioning of a particular individual. Most of the climate change initiatives undertaken are designed with an assumption that every individual have the same conversion factors. The assumption is that since they have the same conversion factors, the resource distributed will be converted to better adaptive capacity. However, it have been seen that most of the programs fails to achieve the desired results since there is no assessments of the conversion factors. According to Sen, capability approach can be used as a framework to analyze the status of an individual in a society in terms of its social relation such as well-beings, poverty, freedoms available, development, gender discrimination, and equality (Sen, 1993). The capability approach is a framework, which is "people centered "approach putting human agency at the centre of the framework rather than markets and governments (Drèze & Sen, 2002). It is an opportunity-based theory, which focuses on the options available to an individual (Robeyns, 2003). Therefore, capability approach, which emphasized the importance of conversion factors, opportunities, and choices, can be used as an alternative to climate change adaptation measures since opportunities and choices enlarges the freedoms of an individual to adapt to climate change.

METHODOLOGY

Focus group discussions (FGDs) were held in the selected study sites to get primary information of the impacts of climate change and adaptation strategies of communities. The rationale for discussions with community on climate change adaptation issues is that communities plays an important role in the process of adaptation to cli-

Figure 2. Sections covered for the FGD questionnaire



mate change and hence their perspective needs to be captured in order to design policies for climate change adaptation.

FGD is a technique to collect qualitative information. FGD is a form of discussion comprising small group of 10-12 members, which is moderated. In the group, various issues related to the area of research are discussed. The discussion is done to get a holistic view of the issue under consideration. The questionnaires for the FGDs were designed keeping in the mind the objective of the study, which includes the climate change adaptation policies and capability aspects of the people. It was broadly divided into following section (see figure 2).

The FGDs were conducted with various groups, which include male, female, and mixed (both male and female) groups. To avoid gender bias FGDs were conducted separately with female members so that they are fully represented in the process of policy design (see figure 3).

Figure 3. Participants of the Focus Group Discussion (FGD)

STUDY SITES

Darjeeling district of West Bengal is located in the Indian Eastern Himalayas neighboring Indian State of Sikkim and shares an international border with Nepal in the west and Bhutan in the east. Geographically the district covers an area of 3,149 Square km situated between latitude 27° 13' N to 26° 27' N and longitude 88°53' E to 87°59' E. The district comprises of four Sub-Divisions out of which three, hilly terrain and mountains cover *viz., Darjeeling, Kurseong, and Kalimpong*. The vulnerability index of Darjeeling districts is 3.40 measured at a scale of 5 due to high exposure to shocks, less coping capacity and less resilient (Saha & Bahal, 2013). The hill region of Darjeeling districts has been facing major problem of land-slides especially during monsoon (Government of India, 2010). The district is also highly vulnerable to various natural disasters such as drought, and earthquake. Apart from these vulnerability the districts also faces political instability due the movements for separate State.

Majority of the respondents are primarily engage in agriculture, few of the groups were dependent on tourism industry such as home stay, and drivers while one each FGD were conducted with members from tea garden and cinchona plantation laborers (Table 1).

RESULTS

One of the research aims of this study was to see various Government interventions made in the study region. The Government of West Bengal along with central Government has implemented various schemes in sectors of education, health and sanitation, housing, livelihood. The respondents were of the opinion that although some people have benefitted from such schemes, majority of the people have been left out of the process. Responses from the FGDs are as follows.

Education

The capability approach by Prof Sen, considers education as basic capability that every individual should possess to enhance her or his freedoms. People with higher education have better op-

Table 1. Study sites in Darjeeling

Sl No.	Study Area		Group	Occupation	Vulnerable to	Number of Participants
	Block	GPU				
1	Kalimpong I	Kankebung	Male	Agriculture	Drought	7
2	Kurseong	Makaibari T.E	Female	Tea Garden	Heavy rainfall	10
3	Kalimpong I	Kaffer	Male	Agriculture	Drought	13
4	Kalimpong I	Seokbir	Female	Agriculture	Drought	12
5	Kalimpong I	Primtam	Male	Agriculture	Drought	8
6	Darjeeling Phulbari	Mazua	Mixed	Agriculture	Heavy rainfall	10
7	Darjeeling Phulbari	Relling	Female	Agriculture	Heavy rainfall	12
8	Darjeeling Phulbari	Goke I	Mixed	Agriculture	Heavy rainfall	14
9	Kalimpong II	Kashone	Male	Tourism	Drought	11
10	Rangli Rangliot	Ronchong	Female	Cinchona plantation	Heavy rainfall	10

portunities and choices available to them (Sen, 1999). In terms of climate change, education is considered as an important indicator of adaptive capacity (Adger, Brooks, Bentham, Agnew, & Eriksen, 2004). Therefore, education of an individual plays a crucial role in enhancing freedoms, which in terms will lead to better adaptation to climate change. Keeping this in mind the questionnaire for FGD was framed to see whether people in the study areas have the better opportunities to education as lack of educational facilities increases the vulnerability of the people and limit opportunities available to them.

The responses from the FGDs were that most of the GPUs have only primary (class I-IV) and upper primary schools (class V- VIII) within the GPU except in *Upper Khani* where a secondary school (Class IX-X) is located. There are no senior secondary, college, and university within the locality. Nearest senior secondary schools are located at an average distance of five Kms. Most of the students drop out after completion of primary school. In some of the region, Christian missionaries have started school. However, most of the people cannot afford to send their children in such schools due to high incidence of poverty. Although the literacy rate of Darjeeling districts is 79.56% (Government of India, 2011), however this data includes persons who can only read and write. The percentage of people attaining higher education is very less as seen from the responses. The highest educational levels attained by people in the regions are graduates. However, the numbers of graduates are negligible compared to the number of illiterate in the region. Most of the schools also do not have permanent teachers and are appointed on ad hoc basis. Compared to male, the female members remain neglected the most in terms of education. Due the engagement of the female child in household activities, lack of proper sanitation facilities in school and long distance to schools, most of the female children drop out of school.

Education in the region has remained neglected due to various reasons like lack of awareness among people, improper implementation of schemes, poverty, and lack of proper infrastructure in the schools. As a result, the opportunities and choices available to the people in the region have remained stagnant due to lack of awareness among them. Therefore, local communities along with Government agencies needs to take up responsibilities for proper implementation of schemes related to education and encourages education among the general masses in the region.

Health

Climate change and its effects on human health have received considerable attention among researchers (IPCC, 2001). Health conditions and sanitation facilities determine the vulnerability level of an individual or communities to climate change (Brooks, Adger, & Kelly, 2005). As explained in the capability approach, health is also determined as an important indicators in achievement of others capabilities (Ariana & Naveed, 2009). Therefore, accessibility of healthcare facilities among individual plays an important role is adaptation to climate change. This section tries to analyze the facilities of health and sanitation, which includes distance to nearest health center, availability of doctors, and sanitations facilities available to the people.

The respondent of the FGDs were of the opinion that there are no hospitals in the regions. Primary health sub centers which are located within the GPUs are accessible to the people. However, there are no doctors except few nurses which are responsible for the treatment the patient in the study region. The nearest primary health center is on an average 5-10 KMs from the GPUs. According to the State Action plan on Climate Change, there are 51 government hospitals, 230 sub centers, and only 23 public health centers (Government of West Bengal, 2012). The numbers of public health centers (23) in the region are very few compared to the number of GPUs which is 112 in the district. The number of hospitals in the district is less compared to the population of 1,846,823 (Census of India, 2011) of the district. Regarding the availability of doctors in the region, they were of the opinion that doctors visit the region once in a month. In case of emergency they have to take the patient to hospitals which are located in the nearest urban center. The infant mortality rate in the district is 67 out of 1000 (Government of West Bengal, 2014). Government schemes like the national rural health mission have been implemented in the region. However, the respondent from the FGDs felt that it is yet to benefit from such schemes. On questions related to whether there is an increase of diseases in the region compared to few years back, the respondents were of the opinion that there is an increase of diseases like diarrhea, liver problem, diabetics, high pressure, jaundice, and gastric. According to report on action plan on climate change prepared by Government of West Bengal, diarrhea and respiratory diseases are the most prevalent diseases in the district (Government of West Bengal, 2012). Most of the people in the study region have access to sanitation facilities with enclosed pits while few of them go for open defecation. Government schemes like total sanitation campaign (TCS) have been implemented in the region. However, most of the toilets build in the region are self-financed and only few have benefitted from the TCS schemes.

From the above discussion, it is seen that although sanitation facilities in the region are satisfactory, medical facilities have remain neglected in the region. As health of the people plays an important role in overall development of the people, utmost importance should be paid in improving and upgrading the present medical facilities available to the people in the region. Having better health and health care facilities among people in the study region would lead to overall development of the people which in turn will help to better adapt to climate change.

Housing

Housing and infrastructure plays a crucial role in measuring a human development. Housing is considered as an important indicator of quality of life. To get an overview of the people's living standard and its capacity to withstand climate change, the component of housing were included in the survey questionnaire. Components such as types of housing, material used for building houses, respondent's opinion on the strength of the houses to natural disasters, and government schemes on housing were discussed. Based on the responses from the focus group, it was found that most of the houses in the study areas were mostly semi pucca and Kutcha (Figure 4). Only few of the household had pucca houses. The materials used for building the roof and wall of the houses are wood, bamboo, tin and stone. The respondents felt that the present housing type they live in are not strong enough to withstand natural disasters like earthquake and strong wind. Therefore people are constantly living in fear to occurrence of natural disasters; however they do not have the sufficient resources and income to build strong houses resilient to natural disasters. Housing schemes such as economically weaker section housing scheme (EWS housing schemes) funded by Government of West Bengal along with the centrally funded housing scheme like Indira Awass Yojna have been implemented in the region. However, only few people have benefitted from the housing schemes such as Indira Awass Yojna (Rs.275000), EWS (economically weaker section) (Rs. 170000) etc. The response from the FGDs shows that people are highly dependent on Government schemes for building their houses since they do not have the sufficient fund. They are also highly vulnerable in case of occurrence of natural disasters in the region. Since housing is one of the basic capabilities which should be guaranteed to every individual in the society, therefore emphasized should be given to quality of houses. Housing schemes sponsored by both

Figure 4. Type of housing in the study sites

Central as well as State Government needs to be implemented with transparency, accountability, and dedication. Lacks of awareness among the rural communities have also lead to failure in implementation of the schemes. Many of the respondents were unaware about the housing schemes as well the procedures for availing the schemes. Creating awareness among the local communities will also help in better implementation of the housing scheme.

Livelihood

The impacts of climate change will have greater burden on rural communities depending on climatic sensitive sectors like agriculture, livestock, fisheries and tourism. These sectors are vulnerable due to high dependence on climate and weather (Dev, 2011). Therefore, agricultural dependent household will have greater burden to the impacts of climate change compared to non-agriculture dependent household. Most of the people in the study sites where the FGDs were conducted are highly dependent on agriculture, livestock, and tourism industry. In two of the selected study sites people work in tea garden (*Makaibari GPU*) and cinchona plantation (*Ronchong GPU*). Discussions were held to see if climate change has any impacts on the livelihood of the people in the study region.

Result of the focus group discussion shows that traditional methods of cultivation is the main occupation undertaken by the people while few of the villages have tourism and daily wage laborers as main occupation. A study conducted by Chaudhary et.al. (2011) reveals that the pattern of agriculture in the district have changed due to the impacts of climate change. There are incidences of news pests and weeds seen in the agricultural field (Chaudhary, Rai, Wangdi, & Bawa, 2011). Although majority of the people does not have an option for secondary occupation, few of them have taken up working as daily wage laborers as secondary occupation. People do not have an opportunities and choices available for employment diversification. Therefore, they are still in the same occupations, which have been followed since generations. They have cited poor market access, poor education, and low-income, lack of proper training and lack of awareness as major barriers to livelihood diversification. Under the central Government schemes such as Mahatma Gandhi National Rural employment Guaranteed Acts- 2005 (MGNREGA), some members of household are employed as daily wage laborers since there are no skilled workers in the village.

They are paid Rs 136/- per day. However, they have complained that the payment process takes minimum of 6 months to be processed. Only one members of household gets job card to work under MGNREGA. Recently people have formed self-help groups (SHG) to generate revenue by lending money at interest to people in need. As a result of poor livelihood opportunities in the region, people are also taking up migration as an option to cope with the present decline in agricultural activities. As study conducted by Sharma (2014) cited uneven values of land properties and low daily wage rate as a reason for people migrating from the districts to urban areas (Sharma, 2014).

In the study area where people work as daily wage laborers in tea gardens and cinchona plantation, they were of the opinion that wage they get are just sufficient for subsistence and not other purposes such as education, health etc. Although the tea garden (Makaibari T.E) provides schooling for the children, however there is not provision for higher education. Respondent in the cinchona plantation areas which under the Government of West Bengal felt that the industry has failed to provide regular work to the people as it is no longer making profit. Many people have to move out looking for jobs outside the locality while some of them have started home stay for tourist.

Based on the above discussion with the people in the study sites, it is found that people are highly vulnerable as their only source of income, which is cultivation have been no longer profitable and choices and opportunities available to them are limited. Therefore there is a serious need for diversification of occupation and also introduction of technology in cultivation. Skill development workshops can be one of the options which might be beneficial to the people as lack of skill to work in different profession has been cited as one of the reason for moving on to a different professions. Having better livelihood among people will lead to better quality of live which will enhance better adaptation to climate change.

The next objective of the study was to see whether social norms and customs limit community's ability to participate in and benefit from the intervention. Climate change policies are likely to fail if social norms and customs are ignored

Table 2. Summary of the findings from the study

Sl. No.	Sectors	Findings	Recommendation
1	Education	• Only primary schools within the GPUs • No facilities for higher education • School dropout rate high • High female child dropout • Ad-hoc teachers in school	Proper implementation of Government sponsored project like Sarba Siksha Abhijan and right to education (RTE), create awareness among local communities
2	Health	• No Hospitals within the GPUs • Public sub center located within the GPU • Doctors not present • Nurse on duty in the public sub center • Occurrence of diseases like diarrhea, liver problem, diabetics, high pressure, jaundice, and gastric	Improving and upgrading the present medical facilities available to the people in the region. Rural posting of doctors necessary. Proper implementation of NRHM schemes.
3	Housing	• Mostly semi pucca and Kutcha houses • Only few have benefitted from Government sponsored housing schemes	Transparency, accountability, and dedication in the implementation of housing schemes. Create awareness among the rural communities of the various schemes.
4	Livelihood	• Agriculture main occupation • Agriculture no longer profitable • Daily wage labor as an secondary occupation • Migration as an adaptation to failure in agriculture	Provision for employment diversification in the region. Training for skill development among local communities necessary.

(Alló & Loureiro, 2014). Social institutions limit and restrict communities' ability especially that of women in the process of implementation of projects. It restricts women's decision-making power and status in the household and family; it also limits women's access to participation and voice in the public and social sphere; this to some extent is due to limited access to education and economic opportunities. While development projects are important and are definitely needed, it is also important to understand that people especially women have fail to benefits due to due to social and cultural norms. To enhance the adaptive capacity of local communities emphasized needs to focus on the women since they play an important role in the functioning of a family as well the society. Based on the focus group discussion, it was seen that various steps have been taken up by the Government of West Bengal as well as by NGOs to empower the women in the study region. However a few sections of the women in the study region have benefitted under self-help group (SHG) as women fails to take part due household activities. These self-help groups are formed with an aim to generate employment among rural women in the region. However, the only activity that the SHG in the study area are engaged is the cash deposit within the members and lent the cash to other members during emergency needs at a certain interest. Although the aim of the SHG was empowering the women by generating employment, most of the SHG in the study region have remained non-functional. The respondents also mentioned that although women get an opportunity to work under the MGNREGA schemes, it has not benefitted much as it fails to build skills among women. They were of the opinion that although MGNREGA has given them short term benefits in the form income generation, in the long they felt that their future is blink due to lack of skill development among women in the region. In terms of schooling for the girl child, the respondents have felt that due to lack of facilities for higher education and sanitation, many of the girls fail to pursue higher education after schooling. Also they were of the opinion that social norms like early child marriage have prevented girl child in attainting higher education in the region. Therefore, there is a need for providing better facilities and creating awareness of the importance of education among local communities in the study region. Although the overall picture of the study regions seems to be gender equal society, due to various social norms and practices, there are still complain of women discrimination in the region in the form of domestic violence, medical negligence, and early marriages.

CONCLUSION

Climate change policies play an important role in building adaptation to climate change. It should be integrated in all areas of public policy, particularly economic and social policies (OECD, 2007). The initiatives taken by the Government in developing countries to enhance the adaptive capacity of the local communities have failed due to lack of proper designing of the projects. Most of the development projects focus on short-term measures like income, resources, and assets. This type of intervention fails to build capability among communities in the society. It makes a particular community more dependent thereby restricting their independence and empowerment. The aim of such development projects should be to enhance the overall capabilities of the communities so that people have the capacity to withstand the impact of climate change in the future. It should be designed keeping in mind the weakest section of the society. Capabilities approach emphasized the importance of various conversion factors like social, political, economic as well as environmental factors in converting particular resources in functioning.

Therefore, development projects based only on resources and assets may fail to benefit the poor due to lack of conversion factors. Although various projects have been implemented in the study region, they have failed to benefit large section of the population. The projects implemented mainly focuses on the distribution of resources and income rather than focusing on conversion factors. Due to variation in capability among different section of the society most of the projects fails to achieve desired result. Important projects like on education and health have failed due to lack of proper infrastructure in the region. Lack of awareness, transparency, gender equality, and proper identification of deserving beneficiaries has come as a hindrance in the successful implementation of the projects. Therefore, this study recommends designing and implementation of projects taking into consideration various conversion factors available to the people.

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Section 10

Industry

Chapter 24
A Framework for Understanding Adaptation by Manufacturing Industries

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ABSTRACT

This chapter discusses what constitutes adaptation responses by firms in the face of climate change. There are four integral components of adaptation activities undertaken by firms: assessment of risk, understanding of vulnerability, understanding the regulatory barriers to overcome the vulnerability, and, finally, adoption of policies to overcome the vulnerability. While it is easy to understand these components separately, their interdependencies make the overall picture more complicated. Also complicating the issue is the fact that most small and medium firms do not have the capacity and resources to predict the impact of such changes on their operations, and hence, to quickly make the adjustments necessary to overcome them. The response of firms also depends on the nature of the climate risk they face, whether it is sea-level rise, or temperature rise.

INTRODUCTION

While adaptation is not a new concept, adaptation to climate change is certainly more rapid and complex in current situations. The IPCC has defined adaptation as, "any adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities".[1] As discussed in West and Brereton (2013), while the boundaries of mitigation are clearly defined and there is a clear metric for assessing the effectiveness of such measures, in the case of adaptation, the boundaries are more ambiguous; also, there are no widely accepted benchmarks for assessing the effectiveness of adaptation. It is in this context, that the adaptive capacity of firms needs to be understood especially in developing countries.

The effect of climate change varies across business structures so adaptation can take many forms. Adaptation is complex and a firm's response will be determined by whether the impact, is in the short or long term. It is therefore essential to understand what constitutes adaptation responses

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by firms in face of climate change. Four components are integral to a firm's adaptation activities: assessment of risk, understanding of vulnerability, understanding the regulatory barriers to overcome the vulnerability, and, finally, adoption of policies to overcome the vulnerability. While it is easy to understand these components separately, the overall picture is more complicated, since there are interdependencies between these components. Also complicating the issue is the fact that the majority of small and medium firms do not have the capacity and resources to predict the impact of climate changes on their operations and hence quickly make the adjustments necessary to overcome these challenges.

This chapter will discuss the changes that firms need to make or, are making, in the context of climate change and situate it in the organizational structure of a firm. For that, it is necessary first to understand what adaptation means at the level of a firm. As adaptation in a firm relates to business strategy, it is important to understand adaptation in that context, since governments and international organizations might think of the issue differently (Nitkin et al. 2010).

BACKGROUND

Definition of Adaptation

Adaptation to climate change has been defined as any adjustment, whether passive, reactive, or anticipatory, and is "concerned with the responses to both, the adverse and positive, effects of climate change". The Stern Review (Stern, 2006) stated, 'Adaptation is the only response available for the impacts that will occur over the next several decades before mitigation measures can have an effect.' (p. xxi). It is important to understand that while the benefits of adaptation will be realized immediately, the benefits of mitigation will be relevant in the long term (FAO, 2012).

The first time adaptation was addressed was in the Second Assessment Report (SAR) of the IPCC in 1996 (Moreno et al. 2006). Adaptation was discussed in that document with respect to impacts on forests, rangelands, and health. The concept of adaptation was linked to vulnerability[2] for the first time in the Third Assessment Report in 2001. The determinants of adaptation are listed as economic resources, technology, information and skills, infrastructure, institutions, and equity. However, the link between poverty, the distribution of resources, and empowerment are not addressed and adaptation is viewed as taking place in relation to set of proximate factors that can be addressed without disturbing the social-political set-up (Basset and Fogelman, 2013).

Adaptation in the climate change literature means different things to different people. The IPCC's Fifth Assessment Report, AR5 (2014) underlines the fact that the adaptation literature ascribes different meanings to the terms opportunities, constraints and limits and this increases the ambiguities related to understanding the issue or addressing it (Biesbroek et al. 2013). It also points out that in moving from the general definition, it is important to understand who is adapting, to what are they adapting, and what is the process of adapting (Smit et al. 1999)?

As Smit et al. (2001) note, adaptation refers to, "adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli and their impacts or effects." (p. 881). Adaptive capacity reflects the ability of a system, region or community to adapt to the effects of climate change. This in turn establishes the determinants of adaptive capacity which relate to the economic, social, institutional and technological conditions that facilitate or constrain the development and deployment of adaptive measures. While the term has specific interpretations, in social science, adaptation refers to adjustment by individuals and the collective behavior of socioeconomic systems (in this context, firms).

In the book, *The Environment as Hazard*, Burton et al. (1978) present a hazards model, which views hazards as the negative outcome of the interaction between natural and social systems whose impacts society seeks to diminish through its actions. This framework emerges from the interaction between discrete natural and social systems that are populated by rational actors whose adaptability is a mix of purposeful adjustments. Proximate factors such as technology, location and income levels and institutions drive the adjustment process.

Basset and Fogelman (2013) discuss the concept of adaptation in the climate change literature: according to them, while the concept of adaptation in the 1970s and 1980s was influenced by the natural hazards school which emphasized the biophysical risks, political economy critique of the adaptation concept influenced the concept currently in use in the climate change literature. The political economy critique of the above approach asks how vulnerability is shaped by political economic processes and social relations of production in which constraints, rather than choice, limit adaptive capacities. The analytical framework in this approach has focused on four areas: (1) the voluntarist conceptualization of society in which social process is reduced to the choices of individual decision makers; (2) the emphasis placed on proximate factors (e.g. unsafe conditions), rather than the root cause of risk (social – structural); (3) the inordinate emphasis placed on bio-physical dimensions of natural disasters to the detriment of their social origins; and, (4) conservative political implications of viewing adaptation as an adjustment process to the prevailing political-economic system.

Watts' (1983a, 1983b) theorization of adjustment and adaptation includes individuals whose ability to cope with and adapt is a social process in which political economic dynamics determine the adaptive capability while in Burton et al.'s atomistic world of individual decision makers adaptation to natural hazards occurs through a 'satisficing' process. Thus while the political economy view regarded adaptation as transformation, the hazards school viewed adaptation as adjustment (Bassett and Fogelman, 2013). Pelling (2011) calls this adaptive approach resilience adaptation since it allows existing functions and practices to exist.

Based on Pelling's classification into three adaptation types (resilience, transition and transformation), Basset and Fogelman (2013) have grouped recent journal articles on adaptation. Adjustment adaptation views climate impacts as the major source of vulnerability and draws attention to responses to climate change rather than the social causes of vulnerability. Transformative adaptation emphasizes the importance of understanding the causal structure of vulnerability in different political, economic and environmental contexts as the basis for adaptation planning. The reformist adaptation group draws largely form the transition category of Pelling and occupies the middle ground between the adjustment and transformative adaptation approaches and seeks to alter the rules that create vulnerability by working within the existing system. Most of the 558 articles reviewed by Basset and Fogelman (2013) fell into this category. Articles on interventions and adaptation in this category also deal with elements of vulnerability that defined and shaped those elements. Other articles within this framework dealt with inequalities and vulnerabilities shaped by political economy, much like papers in the transformational adaptation. However, the former were typified by adaptation that altered the rules and decision making process and often centred on the idea of disaster risk, a concept that attempts to synthesize adaptation and development (McGray et al. 2007, Mearns and Norton, 2010). A recurring theme in the climate adaptation literature is that "development is the best form of adaptation". This is important since if adaptation is viewed as an alternative to development, it may not be undertaken at all.

The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance

Climate Change Adaptation (2012), based on an assessment of the literature, said that while the role of development policy in addressing climate change has been recognized the same cannot be said about its underlying causes. It emphasized the importance of social, political, economic and environmental drivers of environmental risk.

The recognition that some climate change had already occurred led the IPCC to consider adjustments that society had made or might make to reduce its vulnerability (Kates, 2000; Schipper, 2006).

This chapter will discuss the changes that firms need to make, or are making, in the context of climate change and situate it in the organizational structure of a firm. For that, it is necessary first to understand what adaptation means at the level of a firm. While there are many definitions of adaptation, especially in the context of firms, there is no coherent analysis of what adaptation means for a firm in terms of its business strategy.

Problems with the Definition

Based on the findings of the Fourth Assessment Report (AR4), and drawing largely from Chapter 17, Assessment of Adaptive Practices, Options, Constraints and Capacity (Adger et al. 2007), it can be concluded that there are substantial limits and barriers to adaptation, particularly in developing countries. For such countries, adaptation constraints are related to their governance structures, quality of national institutions and on-going development challenges. However, constraints exist even in developed countries. Adger et al. (2007) say that adaptive capacity is influenced by entitlements of actors, by larger macro level economic forces driving forces, and trends in globalization. Long term trends in economic development as well as short term dynamics in economic systems can have a significant influence on the capacity of actors to adapt to climate change. Implications of economic constraints vary among sectors – economies that are disproportionately composed of climate sensitive sectors such as agriculture, forestry, and fisheries may be particularly vulnerable to the effects of climate change and may encounter greater constraints on their capacity to adapt.

While there are a lot of papers that have looked climate change adaptation in the context of agriculture or even primary industries (Rickards, 2013), there are very few that have studied adaptation by manufacturing industries. In the case of primary industries (which include agriculture, forestry, freshwater aquaculture, natural resource management, rural communities and value chains) there are some studies. Rickards (2013) reviews this literature to illustrate the thinking necessary to understand adaptation challenges. She argues that while there is a lot of research on these issues, it is fragmented. There is need for refinements to impacts projections and modelling, basic scientific research into how natural elements function and their interaction with possible climate shifts. Also, there is greater need for social science research in adaptation thinking, decision making and practices, to integrate differences in perspectives as well as comprehensive monitoring and assessments of adaptation in action and the factors involved.

Climate Change in the Context of Developing Countries

Developing countries are the most vulnerable to climate change, as noted by the UNFCCC (2007): they have fewer resources to adapt socially, technologically and financially. A number of developing countries already have adaptation plans or are in the process of developing them. Insurance has been identified as an important component of future action on adaptation. As extreme events, land degradation and loss of biodiversity occurs, there is need to develop innovative risk sharing mechanisms and integrate adaptation plans and strategies with the development plans and poverty alleviation programmes of developing countries.

Food Security, Imports of Food and Impact of Climate Change

While the issue of adaptation of agriculture to climate change has been discussed in great length in the literature (IPCC), we briefly discuss it here for two reasons. First, agriculture is of great importance to developing countries, and second, the link between agriculture and manufacturing is also of paramount importance to developing countries. Agriculture constitutes between 20 and 60 percent of GDP in developing countries and the industries and services linked to agriculture in value chains account for over 30 percent of GDP (UNCTAD, 2011). From the point of view of developing countries, food security is an important question as the majority are importers of cereals. As temperatures rise and precipitation patterns change, the differentiated impact of these changes on the major crops (wheat, rice and maize) has been largely discussed as well as the impact of these changes on developing countries (Easterling et al. 2007). As noted by the FAO (2012), climate change adaptation strategies should aim to increase food production in key exporting countries since any significant change in food production has the potential to, directly and indirectly, affect the global and regional availability of food with repercussions on the local and international markets. However, the literature on adaptation and food production has focused less on adaptation to food systems and on value chains or the set of activities that add value as inputs are converted into products (Porter et al. 2014). Again, in the context of developing countries, this could be of great importance.

Climate Change Adaptation by Industries

The issue of adaptation in the context of industries has been examined in Chapter 11: Industry, Energy, Transportation and Adaptation of the IPCC's Second Assessment Report. This chapter notes that certain components of industry, energy and the transport sectors display a greater degree of sensitivity to climate change. Activities sensitive to climate change include transportation, construction, offshore oil and gas production, manufacturing dependent on water, tourism, and industry located in coastal regions or permafrost regions: the effect of climate change on these industries and the transportation sector will vary according to the risk they face. The sectors in agro industries that depend on products such as grain, sugar and rubber are vulnerable to changes in precipitation patterns and intensity of extreme weather events. Sea level rise would, on the other hand, affect the cost of protecting transport infrastructure and industries located in coastal regions. Higher temperatures would reduce the need for heating, and increase that for air conditioning.

The literature examining the effect of heat has been mainly in the context of residential consumers – more research is needed to examine this effect in the case of firms (Auffhammer and Mansur, 2014 and Sudarshan and Tewari, 2014).

Industry: Business Strategy

Most firms and industry adaptation studies focus on the on adaptation relating to changing business conditions due to the emergence of threats from competitors, products and markets. Since survival is the key question that is addressed in this literature, extension of the concept where the trigger is climate impact can be envisaged. However, a distinction needs to be made: a firm's response to a competitor is different from a response to an external stimulus, which affects all firms equally albeit the extent could vary. Firms can respond by pooling resources as many firms do while facing regulatory hurdles. For example, when faced with a ban by the Supreme Court of India on dumping untreated effluent the dyeing industry in Tirupur, installed a common effluent treatment plant.[3]

There are three strands of literature looking into what firms must do to remain competitive:

the strategic choice perspective, environmental determinism perspective, with some trying to combine the two approaches. This third approach tries to present an understanding of how the external changes are interpreted and acted upon by firms (Linneluecke, et al. 2013). In line with the traditional literature, the literature examining the issue of adaptation has looked at the extent to which adaptation is brought about by factors influencing decision making in firms. These factors could be internal to the firm, such as internal resources, capabilities and routines, or external, such as the firm's embededdness in industry, or social, institutional and cultural factors.

Linneluecke, et al. (2012) offers a framework for organizational adaptation and resilience to extreme weather events. It states that while firms have organizational capabilities for addressing challenges arising out of competitive conditions, they are largely not equipped to handle situations arising out of extreme weather events.

Integration with Industry

UKTI (2011) surveyed firms to assess the potential business opportunities and the risks involved in adapting to anticipated climate change in four sectors: financial services, infrastructure and construction, professional services, and agriculture and life sciences. The survey was conducted by the Economist Intelligence Unit on 705 companies, globally. They found that although nine out of ten firms surveyed have suffered from climate change impacts in the past three years, only three were actively planning and making changes within their businesses. The urgency in Asia is the greatest since the climate risk faced there was the highest. Impacts have varied from disruptions so that staff has not been able to come into work, to supply chain disruptions as well as loss in revenues. Others have reported losses in stock and even damage to buildings and equipment. Asian and Latin American firms have reported more supply chain disruptions and lost revenue.

Not all companies assess risks or possible adaptation measures. Companies pay particular attention to physical risk and risks to supply chains and raw materials. Different aspects of awareness of climate changes were identified: recognition of climate risks, engagement in national dialogues or international negotiations, internal training to raise awareness of climate change impacts, and conducting awareness-raising campaigns. While most firms recognized the current and future risks associated with climate change, fewer firms were engaged in actions related to adaptation. Whether climate risks pose a threat to companies operations depends on several factors, including the nature of the climatic phenomenon, the economic sector considered, the business operation concerned, and the primary input factors the company relies on (Lash and Wellington, 2007).

UNEP (2012) notes that only a few companies appear to be taking a thorough look at climate risks and developing a dedicated adaptation strategy. It profiles several cases based on a survey of 72 firms, in 2010, on business perceptives on adaptation. These surveys were conducted in cooperation with the CEO water mandate.[4] Two of the companies profiled, Coca Cola and Hindustan Construction Company have been working in India. Coca Cola conducts a Water Source Vulnerability Assessment for all its plants which includes an inventory of the risks to water resources supplying each plant and used by the surrounding community. HCC takes a 4R approach to water intervention – reduce, reuse, recycle and recharge.

UNDP (2010) developed a tool that follows a step-by-step climate resilience framework inspired by existing good practice risk management that firms could use for adaptation. Ninety percent of companies worldwide agree that they faced climate related impacts, but only 30 percent have responded to the risks. Changing weather and climate conditions can affect the supply of raw materials, interrupt transport and logistics, damage infrastructure and physical assets, reduce revenues, and create other direct and indirect impacts. The climate challenge for businesses is complex since the impacts will vary by sector and location and will depend on the impacts of climate change directly or indirectly through the value chain. This will require companies to analyze the vulnerability to climate for each link and identify the risk for the whole value chain. The risk for each link has to be assessed and how different impacts can have a compounded effect has to be estimated. The opportunities to build climate resilience across the whole value chain have to be identified and the appraisal of the full lifecycle economic benefits-to costs ratio needs to be done. At the same time, the opportunities for new markets to help communities adapt have to be identified. Finally, climate resilient actions need to be implemented in partnership with those who can mutually benefit from such actions.

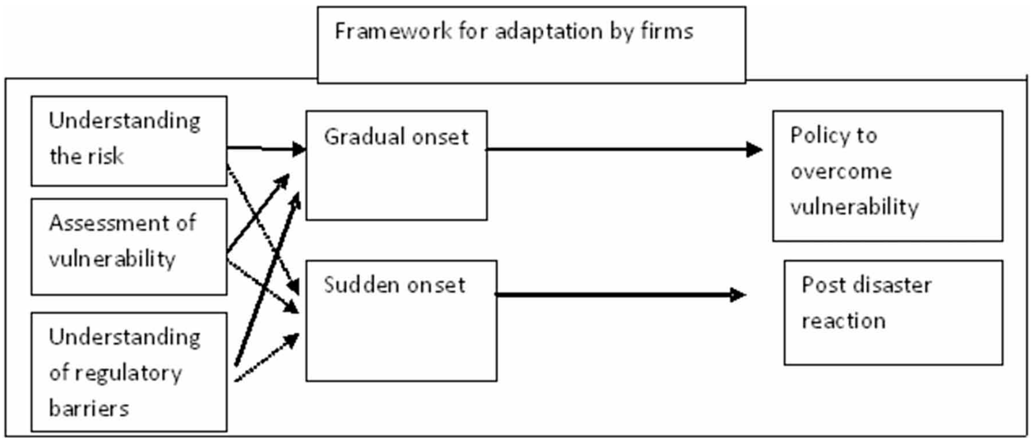
Agrawala et al. (2011) draws on information from 16 case studies of companies active on adaptation issues. The study examines risk awareness, risk assessment and risk management in these firms. Firms may be exposed to different risks as a consequence of climate change; while some of the risks are direct, others are indirect. These risks include physical risks, supply chain and raw material risks, reputational risks, financial risks, product demand risks, regulatory risks, and litigation risks. While there is a high level of awareness among the firms, not all firms perceived that their businesses were vulnerable to them. Firms focused more on risks from extreme events than those of gradual changes. Energy companies, however, were more concerned with gradual changes in temperature as they influence the demand for energy. Companies were generally concerned about possible direct effects of climate change such as damage to company assets and infrastructure, interruptions of operations and business continuity, or damage products due to extreme events, weather related disasters or floods. While companies were less concerned about the indirect effects of climate change risks, such as the decline of raw material availability, increased cost of transport to reach suppliers, increased incidence of diseases affecting the employees ability to work, and shifts in consumer demand that require a company to modify or drop a product line, they are concerned with indirect effects of supply chain risks since they have repercussions on the overall business operations.

Coming to specific cases dealing with this in the context of India, GIZ (2013) has presented two cases of adaptation by micro, small and medium enterprises (MSMEs) in the textiles and the metal working industries. In particular, it looks at the approaches to climate risk assessment and the development of the adaptation measures in these two industries. It makes a distinction between the impact of climate change on the location and buildings, operating processes, logistics and stocks, and observes that while the buildings or the logistics and stocks were not particularly affected by climate change (especially in the metal working industry), the operating processes did show decreased productivity in summer months in both industries. Other challenges faced by the firm related to energy and water supply in both cases, since the need for air conditioning and hence energy rises in the summer and the processes in the textile industry are water intensive.

FRAMEWORK

From the point of view of a firm, there are three components that play a critical role in dealing with climate change adaptation: first, understanding the nature of the climate risk; second, assessing the vulnerability that the firm faces with respect to the risk, and, third, understanding the nature of the regulatory barriers that may arise in overcoming the vulnerability. Once a firm has an understanding of all these aspects, it can, in the case of a gradual onset climate risk, devise a policy to overcome the vulnerability. However, this will not hold in the case of a sudden onset climate risk: depending on the losses that the firm faces in one instance,

Figure 1. Things



it may take adaptive measures to combat the risk in future. The figure depicts the choices from the point of view of a firm.

While numerous studies have looked at the issue of risk (Bierbaum et al. 2013), the second and third parts have not received that much attention. More importantly, the recognition that climate change affects various aspects of a firm's decision making process including its sourcing of raw materials, its inward and outward bound supply chain, as well as the choice of its location, is only beginning to be understood. More research is needed on this aspect, especially with reference to the specific risk that each firm may face in its environment. Also, in the case of SMEs, the role of financing becomes even more critical (Nyugen et al. 2014).

FUTURE RESEARCH DIRECTIONS AND CONCLUSION

Industrial policy in most developing countries aims to generate jobs and build an industrial base as countries transform from agrarian to industrial economies. Most developing countries still remain dependent on agriculture which has deep linkages with the industrial sector of the country. The role of the development plans needs to be re-examined in the case of such countries since there is need to integrate adaptation strategies promoting sustainable development and reducing their risk to the consequences of climate change.

The role of the private sector in adaptation is a topic of debate at international climate negotiations and the Copenhagen Accord sets a goal of developed countries mobilizing $ 100 billion a year by 2020 to finance mitigation and adaptation investments in developing countries. The Green Climate Fund launched at the Conference of Parties 17 in Durban in 2011, includes a facility to finance climate resilience activities in the private sector. While the main sectors emitting GHGs are relatively few: energy, transport, heavy industry and agriculture, adaptation involves a much larger variety of sectors such as human health, water supply, urban planning and costal management (Klein et al. 2005). Integration with the financing of such efforts especially in developing countries is also needed and should be aligned with their development efforts.

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KEY TERMS AND DEFINITIONS

Adaptation: Any adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities.

ENDNOTES

1 http://www.ipcc.ch/publications_and_data/ar4/wg2/en/annexessglossary-a-d.html

2 Vulnerability is associated with the ability of an individual, social group or country to cope with specific risks (Burton et al. 1978).

3 Can be assessed at http://www.twic.co.in/index.php/home/48-industrial-effluent-treatment-a-water-reuser/77-tirupur-textile-effluent-management.html

4 www.ceowatermandate.org/

Chapter 25
Temporal Data Analysis and Mining Methods for Modelling the Climate Change Effects on Malaysia's Oil Palm Yield at Different Regional Scales

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ABSTRACT

Space and time related data generated is becoming ever more voluminous, noisy and heterogeneous outpacing the research efforts in the domain of climate. Nevertheless, this data portrays recent climate/weather change patterns. Thus, insightful approaches are required to overcome the challenges when handling the so called "big data" to unravel the recent unprecedented climate change in particular, its variability, frequency and effects on key crops. Contemporary climate-crop models developed at least two decades ago are found to be unsuitable for analysing complex climate/weather data retrospectively. In this context, the chapter looks at the use of scalable time series analysis, namely ARIMA (Autoregressive integrated moving average) models and data mining techniques to extract new knowledge on the climate change effects on Malaysia's oil palm yield at the regional and administrative divisional scales. The results reveal recent trends and patterns in climate change and its effects on oil palm yield impossible otherwise e.g. Traditional statistical methods alone.

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INTRODUCTION

Research into addressing the major issues relating to the nature, storage, pre-processing, analysis and interpretation of big data generated in the climate domain is severely lagging behind the current data growth rate (Faghmous, 2014). Indeed, there is "a stark contrast from other fields such as advertising and electronic commerce where big data has been a great success story" (Faghmous & Kumar, 2014 p1). Despite this lack of research in this domain, space and time related information continues to grow at unprecedented rates, so are the noise and heterogeneity in the data acquired by a multitude of telemetry in-situ instruments and sensors. With the introduction of more sophisticated data acquisition devices and equipment, such as new satellites and radars, climate and weather data holdings (depositories/ centres) are anticipated to grow exponentially. For instance, from 2004 to 2013, digital archives of National Climatic Data Center (NCDC), the world's largest weather/ climate data archives, grew from 2 to14 petabytes (PB[1]) (NCDC, 2014). Such massive volumes of noisy and heterogeneous data increasingly present more complex constraints when handling and analysing the data especially, using conventional methodologies. The recently acquired climate/weather data in addition to increased volume related issues, also encompasses auto- and cross-correlations between input variables. More specifically, the data presents severe limitations with the existing learning algorithms that make implicit or explicit independence assumptions about the input data.

Besides the lag in research relating to climate data processing and analysis, contemporary climate-crop models are described to be outdated (Rotter, Carter, Olesen, & Porter, 2011). Conventional methods currently in use for modelling climate-crop interactions were developed at least two decades ago. These methods originally designed for prospective analysis of survey data reflect "reductionism[2]". They do not address the major impediments relating to retrospective analysis of "big data" that depict the recent variability in weather and climatic conditions. For instance, the frequency and extremity embedded in the raw data in the form of trends, patterns and correlations cannot be analysed using conventional modelling approaches or techniques (Callebaut, 2012). Hence, *digital ecosystem* approaches (the application of holistic[3]/systems concepts in computing) are required to analyse multi-sourced data sets collectively/ integrated with other data (Mattmann, 2013), in this case with crop yield. This is seen as vital to unravel the recent change patterns in climate and weather to model/predict the change effects on key crops for decision/ policy making at many critical levels and scales i.e., from daily farm management operations to policy making relating to the world food security now and in the near future (UCAR Office of the President Developments and Partnerships, 2014).

Yet another aspect that makes climate-crop modelling more complicated is the fact that climate change effects are observed to be somewhat stochastic depending on the climate-crop regime (Köstner, et al., 2014). The effects could be positive or negative, negligible or extensive depending on the change in the regional climate, to be precise, on the local weather, site quality, and land use and management practices adopted. Hence, any practical measure to adapt to the local weather change by way of plant management practices i.e., to irrigate rain fed crops, extensive knowledge on potential and specific impacts of climate change at the local site, regional, as well as global scales are required. In addition to these factors, different crops respond very differently to the same climate/ weather change, in the case of oil palm, frond emission, flowering and fruit production are the stages that get affected. The stages can also be affected by internal factors i.e., plant age, tolerance to drought, simultaneously reflecting seasonal maxima/ minima. Finally, diseases and pests play a major role in the oil palm production and their effects on oil palm under changing climate too are anticipated to be unprecedented (Paterson, Sariah, & Lima, 2013).

All the above facts reiterate the urgent need for novel, powerful computational frameworks and approaches consisting of scalable methods based on insightful leveraging of emerging fields, such as data science, reinforced by domain specific expertise, to resolve the computational issues and other domain specific problems concurrently. Indeed, there is a pressing need for new methodologies/approaches to store, transmit, pre-process and analyse big data on current climate (annual/monthly) and daily weather on-the-fly in an eloquent way moreover, based on holistic approaches to further our understanding on climate-crop interactions at various spatiotemporal scales. In this context, the chapter looks at the use of scalable time series analysis, namely ARIMAX (Autoregressive integrated moving average with exogenous variables) models and data mining techniques (decision tree and association rules), to gain in-depth knowledge on the effects of climate change on oil palm yield in Malaysia at different spatial scales i.e., East/West Malaysia and then at a more finer scale i.e., administrative divisions of the country.

Literature reviewed for this research on the significance of the oil palm industry in Malaysia and in the world are briefly outlined in the Background section. The section as well looks at the complexities relating to modelling the climate change effects on overall oil palm yield, such as oil palm tree phenology, pests and diseases of oil palm and their damage on oil palm tree production under current and future climate change scenarios. The Related work section elaborates on the research thus far conducted on understanding the climate change effects on oil palm yield in the Malaysian context by others and the authors of this work. The section also reviews the work on other continents, such as South American (Columbia) and South African (Ghana) on the topic. ARIMA model applications to climate-crop data analysis and forecasting as well are outlined in the related work section. The methodology section elaborates on the theory of ARIMA modelling and time series data mining techniques as well as the data sources. The results and discussions section explains the results more specifically, looks at how time series data analysis and mining have been used to enhance climate-crop interaction modelling using already acquired multi-sourced data sets. Finally, conclusions and future research directions are summarised.

BACKGROUND

Oil Palm Industry in Malaysia

The significance of the oil palm industry in Malaysia is of several fold. The socioeconomic implications at both, local and international scenes on the oil palm industry caused by climate change is anticipated to be massive and devastating (Shanmuganathan & Narayanan, 2012). In 2011, Malaysia's total palm oil export was 17.99 million tons, 39.04% of the global export market, second to that of Indonesia's 44% (Willy, undated). The indications are that any change in the current climate capable of causing even a small impact on the production of this world's staple food, could in turn kick off cascading effects on many communities (UNDP, 2011). The main reason for this is that palm seed is the most efficient of all four available major oil source crops, the others being, soybean, rapeseed, and sunflower (Hormaza, Fuquen, & Romero, 2012). Oil extracted from palm seed kernel still holds the largest share, i.e., 27% of the world's oil and fat consumption. Palm oil also has been proven to be the most efficient source of biofuel which has caused some concern over the negative implications this could have on the world food security. The main concern is that agricultural land once used to grow food crops being used for the biofuel sector as a source of biofuel and food crops, rather than as food alone (Sustainable Palm oil Platform, 2014).

Climate Change and the World Oil Palm Industry

Oil palm (*Elaeis guineensis*) is a tropical tree crop and the ideal climatic conditions for optimal growth for this crop are: rainfall 1780-2280mm per annum with no or a 2-4 month dry period however, the palm grows in areas with annual rainfall of 640 mm or 4200 mm (Verheye, 200?; Duke, 1983) and this shows the crop's drought tolerance. Despite the fact that dry periods of more than 2-3 months do not specifically damage vegetative growth, their effects on the production and quality of the fruit bunches is extensive. Very high yields can be achieved with well distributed rain throughout the year with the monthly optimum not exceeding 150 mm. Mean annual rainfall deficits not exceeding 600-650 mm annually is one of the main conditions required for oil palm. Ideal mean maximum and minimum temperatures required are: 30-32 and 21-24 ^{o}C respectively. Oil palm productivity and growth are severely reduced at below 20 ^{o}C for prolonged periods, growth may cease below 15 ^{o}C. Oil palm is affected by high temperatures with photochemical efficiency reduced at above 35 ^{o}C. The plant grows on a wide range of tropical soils, pH 4-8 range is fine if sufficiently moist (Duke, 1983) though the oil palm plant needs open areas, as it cannot compete with faster-growing trees and it does not grow under continuous flooding for a prolonged period either. The oil palm tree tolerates fluctuating water tables with periods of standing water and so may cope with flooding episodes from future climate change to an extent but it may cause a reduction in yield.

Natural habitats for oil palm are: swamps, riverbanks and other areas that are too wet for dicotyledonous trees of the tropical rain forest. Currently higher altitudes above 500-600 m and latitudes above 10^{o} are not suited for this crop. Hence, under the current global climatic conditions, the equatorial belt presents the most suitable habitats for oil palm cultivation (Paterson, Sariah, & Lima, 2013). Accordingly, the tropical rainforest belt of West Africa between 10^{o}N and 10^{o}S and the 200-300 km coastal belt from approximately 15^{o}N to 15^{o}S besides the Southeast Asian and South American, are seen as the best regions for oil palm cultivation. The world's top oil-palm-producing countries, Indonesia, Malaysia, Nigeria, Democratic Republic of the Congo, the Ivory Coast, Brazil, Colombia, Costa Rica, and Ecuador, are all in these regions (Corley & Tinker, 2003). Finally, oil palm yield is not only determined by vegetative growth and production, there are many other factors, and one of them is the way how pests and diseases are controlled/ eradicated/ managed.

In view of the above climatic and other environmental conditions required for ideal plant growth and production in oil palm, and the recent climate change that is described to be significantly stochastic in terms of the frequency, extremity, geographical distribution of the extreme events, a thorough investigation into the issues is timely and very important not just to the oil palm producing nations but to the whole world. In this context, the observed impacts of recent erratic climate/ extreme weather change on the oil palm tree phenology, production, and pests and diseases in the Malaysian context are discussed here onwards in this section.

Oil Palm Tree Phenology

Similar to any other tropical plants, oil palm tree phenology and life cycle as well could be defined by growth stages, such as leaf development, stem elongation, inflorescence emergence (frond emergence), flower sex differentiation, central arrow development, flower development and abortion, flowering (and anthesis), development of fruit, ripening of fruit and senescence (leaves and the tree) (HormazaI, FuquenII, & Mauri, 2012). Among these stages, flowering (and anthesis) and fruit production exhibit seasonal maxima caused by unknown reasons (Legros, et al., 2009). Prolonged droughts, and heavy rains confound the rhythms

Table 1. Events and stages in oil palm inflorescence development and postulated internal negative feedback loops based on (Henson & Dolmat, 2004; Legros, 2009)

Development events and stages

Events	Frond emergence or initial stage:	*Sex differentiation or bunch formation	Central arrow development/ frond emission	**Flower development and abortion	Flower opening and anthesis	Fruit maturation
Months preceding harvest	36-24	33-18	22-12	20-10	12-5	6-0
feedback						

*Sex differentiation or bunch formation and **Flower development and abortion are the two stages that get affected by feedback mechanism in oil palm phenology fruit production cycle.

and fruit production cycle with lagged effects on the fruit production dynamics (table 1). All such effects make the understanding and prediction of oil palm yield even more challenging.

It is argued in (Henson & Dolmat, 2004) that fruit production cycle in oil palm exhibits some form of an observed internal feedback mechanism in addition to the external factors, such as favourable climate. The authors of that work had cited earlier research to support their research results. Based on these arguments, a current high yield will lead to future low yields and vice versa (Table 1). Similar feedback mechanisms of prevailing bunch load have been hypothesised and supported by earlier field experiments since the late 1970s. The mechanisms are described to be regulating flower sex differentiation, abortion and future bunch development stages in terms of the number and mean weight of subsequent bunches. Even though these plant feedback mechanisms could result in a perpetual cycling, they do not account for the annual yield cycles that consist of much longer lag periods. Based on the most probable timings suggested by Corley and co-workers (Henson & Dolmat, 2004), an abortion-controlled cycle has been suggested to have a full (peak-to-peak) cycle length of around 16 months. Meanwhile, a cycle dependent on changes in the flower sex ratio has been suggested to have a full cycle length of at least 30 months. Furthermore, the length of such cycles are expected to be altering themselves as the palm tree ages leading to a gradual decline in frond emission rate. Such cycles need to interact and overlap to give rise to annual peaks. Furthermore, the different phases of the yield cycle can be shifted even following some treatments, such as disbudding, that may be operating via bunch load. The phase shifts are described to be transient and reset by other external factors, such as prolonged droughts), all of which as stated in (Legros, et al., 2009) make modelling palm oil yield cycle, and yield forecasting under different weather conditions i.e., current and potential climate extremes, and treatments ever more challenging.

Pests and Diseases of Oil Palm

In addition to the above factors localised losses in oil palm yield caused by diseases and pests can be substantial if high pest populations or outbreaks occur persistently (Darus & Wahid, 2001?). The major pests that can cause severe economic damage on oil palm yield are; bagworms, nettle caterpillars, bunch moths, rhinoceros beetle, cockroaches and rats. Meanwhile, the major damaging diseases are; *Fusarium* and *Ganederma*, the former possess a huge threat to the oil palm plantation sector in South Africa. The latter is a major problem in Malaysian plantations. If the current trends in climate change continue, tropical "land will become increasingly unsuitable for growing oil palm and the plants will become stressed allowing ingress of fungal diseases. New land will be[come] increasingly suitable where the environmental conditions are less severe than in the tropics. Novel diseases may threaten the crop" (Paterson, Sariah, & Lima, 2013) p1. This very fact has been identified as one of the emerging topics for further research in the sector especially, for the traditional smallholder oil palm economies in various countries (Social Impact Advisors, ?). In order to manage the pests and diseases of oil palm, over the years, a practice called intensive integrated pest management (IPM [4]) of various key species has become an integral part of the oil palm industry in order to minimise damage from these species to the industry.

With that introduction to oil palm background in the next section, recent work on modelling climate change effects on oil palm tree phenology and yield in the Malaysian as well as other country contexts, and a few recent ARIMA models applied to natural phenomena forecasting are presented.

RELATED WORK

In a pioneering study (Cadena, et al., 2006) titled "Relationship between the 1997/98 El Niño and 1999/2001 La Niña events and oil palm tree production", the authors studied the effects of the two extreme events in local climate and on oil palm tree production in Tumaco situated in the Colombia's Pacific coast. Through that study, it was established that in the past El Niño and La Niña events had had lagged and conflicting impacts on oil palm yields in that region. El Niño experienced in 1997/98 was found to be a favourable event with the maximum correlation within the timeframe studied showing an increased production observed in 2.6 years. Meanwhile, La Niña of 1999/2000 that caused severe droughts, resulted in the highest negative impact i.e., reduced oil palm production in 2002, two years later.

Research presented in (Shanmuganathan & Narayanan, 2012; Shanmuganathan S., Narayanan, Mohammed, Ibrahim, & Khalid, 2014) looked at the lagged effects of temperature on oil palm yield (monthly) at different spatial scales using statistical regression and a hybrid approach of statistical regression and data mining techniques. The former looked at the effects in the West and East Malaysia (Figure 1) and the latter looked at the effects among the different Malaysian administrative divisions (Figure 10). The statistical linear regression test results of the former showed that the July 2005, December 2005 and June 2006 extreme monthly temperatures (i.e., anomalies) that had affected the West Malaysia's oil palm yield did not affect that of the East due to negative deviations (cooler) experienced in temperature in the East. However, in January 2009 and June 2010, both regions experienced positive deviations in the monthly temperature and they had caused negative impacts on the monthly oil palm yields of both East and West of Malaysia that lie on either side of the South China Sea, the effects being lagged by 25 and 17 months respectively. The regression test results of East and West Malaysia's monthly yield against 36 lag variables, monthly temperature anomalies of month -7, -13, -19 (- indicates months prior to harvest) were found to be the predictors for yield.

In the latter work (Shanmuganathan S., Narayanan, Mohammed, Ibrahim, & Khalid, 2014), the results of a linear statistical regression test ran on all ten administrative divisional yields together against their respective 36 lag variables (average monthly temperatures) were presented. Of all the 36 lag variables studied, average temperature of months -9, -13 and -8 (or months preceding harvest) were found to be the predictors for monthly oil palm yield at this scale. The -13 to -9 months /preceding harvest is the time period that flower opening and anthesis occur based on a 36 month fruit production cycle in oil palm, adopted in that study as well as the others. Meanwhile, in the regressions ran using individual administrative divisional yields separately against their respective 36 lag variables, different combinations of lag variables were produced as predictors however, all the regions had either the flower opening and anthesis stage (between -13 and -6) alone or combined with some other months relating to the initial stage/ flower sex determination (-33 and -29), as predictors. The timing supports the feedback mechanism, i.e., high yields regulating the inflorescence abortion and sex determination stages, leading to future low yields (Table 1), a theory postulated and supported by experimental results (Henson & Dolmat, 2004) (see section Oil palm tree phenology). In the administrative division scale study, WEKA J48 and JRip rules (association and decision tree rules respectively) showed the common months and their effects as well as some unique month/s specific to the administrative divisions analysed. Based on this fact, it was concluded that any crop forecasting should be regionalised to increase the accuracy of forecasting, size of region being suggested as dependent upon local environmental conditions, such as terrain.

In (Keong & Keng, 2012), the key physiological stages of the 36-month oil palm flowering cycle, namely, flower sex determination and abortion, were found to be affected by soil moisture. The time periods relating to these stages were identified as 9-11 and 22-23 months before harvest respectively. Hence, the study concluded that soil moisture values at particular months prior to harvest as useful indicators for modelling the oil palm yield. Based on the statistical regression test results obtained, lag variables 9-24 monthly percentages in available water holding capacity (%AWHC) were found to be the predictors for monthly oil palm yield. Furthermore, in ascending yielding phase, palm tree age was suggested as an important factor when determining the physiological efficiency (yield increase per kg nutrient uptake). The model indicated that 68% of the variability in monthly Full Fruit Bunch (FFB) yield was well represented by the regression equation.

A Ghanaian study presented in (Stenek, 2011) looked at the potential climate - related risks for Ghana Oil Palm Development Company (GOPDC) in that country. The company owned at the time of the study, two oil palm plantations at Kwae and Okumaning in Ghana's Eastern Region. It also owned a mill and refinery at Kwae, where oil palm FFB was processed into crude palm oil (CPO) and palm kernel oil (PKO), as well as refined products (primarily olein and stearin). The report found the temperature in that part of the country where oil palm companies were situated as showing steady increase with high confidence. Despite a less clear picture with respect to changes in seasonal rainfall, about half the models looked at, projected future increases in rainfall while the rest showed decreases over that part of Ghana. The confidence was high for increased rainfall intensity, meaning that a greater proportion of total rainfall would fall during heavy events. In addition, the study identified a few more important issues that would have far reaching implications with regard to oil palm fruit production and oil refinery operations. For example, effects of climate change on the important oil palm pollinator, *E. kamerunicus* cannot be ignored. Three main operations were undertaken for that GOPDC study and they were: oil palm plantation development, processing of FFBs in the mill to produce crude palm oil (CPO), and palm kernel oil (PKO) and refining/fractionation of CPO into higher value products. Plantation development activities included seed germination, plant cultivation in the pre-nursery, nursery and main plantation, non-mechanized harvesting and collection of FFBs and transportation of FFBs to the mill. Hence, as suggested in the study and many others, there was an urgent need for additional research to look into the climate change effects taking into consideration of a whole range of issues from oil palm seed germination to palm oil refining including other factors, such as palm pollinators, pest and disease control.

In (Sheil, et al., 2009) on a related topic "The impacts and opportunities of oil palm in Southeast Asia what do we know and what do we need to know?" it was found that the demand for palm oil as *high* especially, for food and other uses. Understandably, the authors predicted the demand for oil palm to rise as China, India and other similar economies developed. Also, the authors saw the possibilities of oil palm to be managed less intensively to provide for local fuel needs nearer to where the crops were to be grown especially, in less accessible locations where the costs of importing fuel would be high. The report as well envisaged the future trends of oil palm, similar to any new and profitable land use system, to be determined by a variety of factors including land availability, access to labour, capital and technology, regulation, investments, security, competing land uses and alternative sources of income-balanced with market trends, especially, demand and consumer perceptions. Even though many of these factors have been extensively investigated in the context of other crops and innovations (Angelsen & Kaimowitz, 2001), the need for a clearer examination in the context of oil palm in its various guises was reiterated. Among the many generic key issues identified for better oil palm production were; the importance of good planning, management, transparency and accountability.

A more recent so-called fact sheet by (Union of Concerned Scientists, 2013?) that described palm oil as ubiquitous in the global marketplace stated this world's cheapest edible oil among the major contributors to global warming. In view of this main concern, four solutions were suggested in order to conserve natural resources, protect biodiversity, and reduce the risk of climate change. The solutions were anticipated to transform the palm oil industry as current palm oil production methods were found to be destroying carbon-rich tropical forests and peat lands. The four solutions suggested were: improve yields and plant on degraded land, governments formulate their biofuels policies to avoid unintended consequences and to ensure that critical climate goals would be met, companies in palm oil-related businesses act to ensure that none of their raw materials contribute to tropical deforestation or peat land depletion and finally consumers exert their influence.

ARIMA Models for Natural Phenomena Forecasting

More recently, there have been attempts to fit ARIMA (or Autoregressive Integrated Moving Average) models to time series data for understanding and forecasting natural phenomena and a few such attempts related to this research are outlined.

In (García-Mozo, Yaezel, Oteros, & Galan, 2014), ARIMA models were found to have provided the best approach to forecasting future phenological trends in pollen production in Córdoba, Spain in Southern Europe. The study found ARIMA model predictions to be displaying a better goodness-of-fit than those derived from linear regression for Pollen Season Duration (PSD), Pollen Season Start, and Pollen Index, for a period of five years (2011- 2016). Furthermore, from the findings of that study, it was established that the olive reproductive cycle has been undergoing considerable change over the last 30 years (1982–2011) due to climate change. Based on the ARIMA model predictions, it was concluded that ARIMA models could provide reliable trend projections for future years taking into account the internal fluctuations in time series.

ARIMA models were tested in (Verma, Koehler, & Goyal, 2012) for forecasting the yields of winter/ spring wheat, winter / spring barley, oat, rye, rapeseed, maize and sugar beet crops for the last four/five decades in Marienborn, Germany. The study found ARIMA models to be more accurate for forecasting short term crop yield estimates. Using an ARIMA model approach based on Box-Jenkins method, Ghana's annual coffee production was forecast to continue to decrease over the succeeding five years in 2012 unless drastic measures were taken to change the crop cultivation methods and practices (Harris, Abdul-Aziz, & Avuglah, 2012). Similarly, in (Jian, Zhao, Yi-Ping, Mei-Bian, & Dean, 2012) ARIMA modelling results proved that temperature, humidity, wind velocity, and barometric pressure were to be significant predictors for forecasting ultrafine particle (UFP) and particulate matter 1.0 (PM1.0) concentrations. In the latter study, the other independent parameters such as wind direction and rainfall used did not show statistically significant impact on the pollutants. The study was aimed at modelling the effects of meteorological factors on the two submicron particle concentrations under busy traffic scenarios by a roadside in Hangzhou, China.

Final results of (Jia, Zhao, Deng, & Duan, 2010) suggested that the ARIMA model approach investigated to be an efficient method for simulating and predicting ecological footprint (EF) in the Henan Province of China for decision-making especially, for better planning of the ecological balance at the regional scale for a sustainable future. In (Bako, Rusiman, Ibrahim, & Hazel Monica, 2013), the authors constructed an ARIMA model using fish catch data of two fish species to predict the fish catch described to be an important problem in the fisheries sector. The authors of that paper used Box and Jenkins method stating it as among the most effective and prominent methods for analysing time series data. By applying the Box-Jenkins methodology a Seasonal Autoregressive Integrated Moving Average (SARIMA) model for monthly catches of two fish species for a period of five years (2007 – 2011) was constructed. The seasonal ARIMA and SARIMA models were found to be best fit and confirmed by the Ljung-Box test. The models were then used to forecast 5 months upcoming catches of *Trichiurus lepturus* (Ikan Selayor) and *Amblygaster leiogaster* (Tambun Beluru) fish species. The results of the study were stated as would be of help to decision-makers when establishing priorities in terms of fisheries management.

In (Suresh & Krishna Priya,, 2011), the authors attempted to forecast the sugarcane area, production and productivity of Tamil Nadu through fitting univariate ARIMA models using data on the three factors collected for a period of 57 years (1950–2007). A first order ARIMA model was found to be suitable for sugarcane area and productivity. Meanwhile, a second order ARIMA model was found to be appropriate for modelling sugarcane production. The models were validated using a test data set. They were then used to forecast values for sugarcane area, production and productivity for subsequent years. ARIMA models have been successfully applied to weather forecasting as well. In (Narayanan, Basistha, Sarka, & Sachdevaa, 2013), an ARIMA model univariate forecast for pre-monsoon months indicated that there was a significant rise in the pre-monsoon rainfall over the northwest part of western India.

With that outline on modelling climate change effects on oil palm in Malaysia as well as other palm oil producing nations using conventional data analysis and statistical methods, and finally on a few applications of ARIMA models for forecasting various natural phenomena, in the next section, time series data analysis issues and ARIMA model development are presented. The main purpose of this study is to investigate the use of ARIMAX models and time series data mining methods to further our understanding on recent climate change effects on oil palm yield in the Malaysian context at different spatial scales using short and long term time series data sets. The scales studied are 1) East and West and 2) administrative divisions of, Malaysia.

THE METHODOLOGY

Time Series Analysis and Mining

Time series analyses are aimed at developing mathematical models that provide plausible descriptions for sample data sets observed sequentially over time, called time series data (Shumway & Stoffer, 2014). Daily exchange rate, monthly rainfall, real-estate company property sales in the last ten years, observations/ events of natural phenomena, scientific and engineering experiments, and medical treatments over a stipulated period at a regular time interval are some examples of time series data. Time-series analysis is also useful when forecasting future patterns of events as well as comparing series of different kinds of events (Tabachnick & Fidell, 2008). Meanwhile, time series data mining techniques are aimed at enhancing our natural ability to visualising the shape of the data and thereby to identifying similarities between patterns in different time scales (Esling & Agon, 2012). In general, humans rely on complex schemes to perform complex tasks. Nevertheless, by avoiding the focus on small fluctuations, a notion of shape has been used to identify similarities between patterns on various time scales. Major time-series-related tasks can be categorised into seven groups and they are: 1) query by content, 2) anomaly detection, 3) motif discovery, 4) prediction, 5) clustering, 6) classification and 7) segmentation. Despite the vast amount of research undertaken on this topic, the view is that "the research has not been driven so much by actual problems but by an interest in proposing new approaches" (Esling, et al., 2012:1). In (Ratanamahatana, et al., 2005), a feature extraction step has been suggested to transform time series data into a high level representation. In fact, there has been a multitude of representations successfully tested and implemented for this purpose and they are: spectral transforms, wavelets transforms piecewise, polynomials, Eigen functions and symbolic mappings. These and the other similar high level representations are stated as useful not only to transform raw data into a manageable form, but also to enhance the storage, transmission, and computation of massive dataset with ease.

The ARIMA Models

Similar to statistical regression analyses, in the ARIMA model construction process as well, a score is decomposed into several potential elements (Tabachnick & Fidell, 2008). One of such elements is a random process or shock that is compared to the error in other analyses. There are other potential patterns in trends over time overlaying this random element and they can be:

1. Linear (where the mean is steadily increasing/ decreasing over time)
2. Quadratic (where the mean first increases and then decreases over time/ show a reverse) or
3. Something more complicated.

Then, there could be a second potential pattern that lingers the effects of earlier scores. Finally, there could be a third potential pattern that lingers the effects of earlier shocks. Furthermore, these patterns are not mutually exclusive, two or all three can be superimposed on the random process.

The ARIMA model construction process consists of three iterative stages and they are; *identification*, *estimation*, and *diagnosis*. The three stages are used to analyse the time series data looking for patterns in trends in the data. In the *identification* stage, autocorrelation functions

(ACFs) and partial autocorrelation functions (PACFs) are examined to *identify* the presence of any of the three potential patterns in the data. In long term time series, some measures vary periodically, explained by a term called seasonality. Patterns indicating both periodicity and cyclicity in time series also can be identified using ACFs and PACFs, and accounted for in the model.

The second stage is the *estimation* in which the estimated size of a lingering auto-regressive or moving average effect is tested against the null hypothesis based on Augmented Dickey Fuller test. The third stage is the *diagnosis*, in which residual scores are examined to determine if there are still patterns in the data that are not accounted for. Residual scores give the differences between the scores predicted by the model and the actual scores for the series. If all patterns are accounted for in the model, then the residuals would be random. In time series applications, identifying and modelling the patterns in the data are sufficient to produce an equation, which is then used to predict the future of the process in the *forecasting* step. The ARIMA procedure in SPSS (SPSS IBM Corporation, 1989, 2013.), computes the parameter estimates for a given seasonal or non-seasonal univariate ARIMA model. It also computes the fitted values, forecasting values, and other related variables for the model defined by:

ARIMA (p, d, q) model (1)

where,

p is the auto-regressive (AR) element that represents the lingering effects of preceding scores.

d, is the integrated element that represents trends in the data, and

q is the moving average (MA) element that represents the lingering effects of preceding random shocks.

The auto-regressive and moving average components can be combined to fit yield data to ARIMA models using Box-Jenkins method or other methods.

A seasonal univariate ARIMA $(p,d,q)(P,D,Q)$ model can be defined by

$$\Phi(B)\ [\Delta y_t - \mu] = \Theta(B) a_t \quad t=1,...,N \qquad (2)$$

where,

$$\Phi(B) = \varphi_p\ (B)\Phi P(B),\ \Theta(B) = \theta q\ (B)\Theta Q(B)$$

$\varphi_p\ (B)$ - non-seasonal operator of auto-regressive process AR(p)

$\theta q\ (B)$ - non-seasonal operator of moving average MA(q)

$\Phi P(B)$ - seasonal operator of auto-regressive process AR(P)

$\Theta Q(B)$ - seasonal operator of moving average MA(Q)

d,D – non-seasonal and seasonal orders of differencing;

B – backshift operator

μ is an optional model constant. This constant is also called the stationary series mean, assuming that, after differencing, the series is stationary. Therefore, when there is no constant specified, μ is assumed to be zero.

An optional log scale transformation can be applied to *yt* before the model is fitted. The same symbol, *yt*, is used to denote the series either before or after log scale transformation.

The independent variables $x_1, x_2, \ldots, x_m$ are included in the model and defined by

$$\Phi(B)[\Delta(y_t - \Sigma_{i=1} c_i x_{it}) - \mu] = \Theta(B) a_t \qquad (3)$$

where

c_i, $i=1,2,...,m$, are the regression coefficients for the independent variables.

By adding the external factors (independent variables), the unexplained components of pure ARIMA (dependent data alone) can be accounted for and the transfer function of such an ARIMAX model can be written as,

$$y_t = \mu +- \Sigma_{i=1} V(B)x_t + (1- \Phi B)(1- \Theta B^s)\, a_t$$

where

s - Order of the season
$V(B)X_t$ – the transfer function which allows x to influence y via a distributed lag

The best fit for the time series data (monthly yield of East and West Malaysia) is selected based on RMSE and Normalized BIC values based on Ljung-Box Q method in this study.

The Data

Long Term Yield Data (East and West Malaysia)

Monthly oil palm yield data (FFB in tons/ha) from East and West Malaysia for a 25 year period (1986-2011) obtained from the Malaysia Palm Oil Board (MPOB) was used as the dependent variable in this long term time series study (figures 1 and 4). The dependent variable is analysed along with 72 lag variables, 36 monthly anomalies in temperature and 36 monthly anomalies in precipitation experienced prior to harvest, in the East and West Malaysia. The anomalies for the corresponding grids were extracted from (NOAA, 2012). For more details on the data extraction and pre-processing see (Shanmuganathan & Narayanan, 2012)

Short Term Yield Data (Admin. Divisions of Malaysia)

Monthly oil palm yield data (FFB in tons/ha) for ten of thirteen Malaysian administrative divisions (figure 10) for a period of five years (2007-2011) obtained from Malaysia palm oil board was used as the dependent variable. The short term yield data was analysed along with 36 lag variables (36 monthly average temperatures prior to harvest) in this study. Climate data was not available for three divisions hence, were not included in this study. Global daily temperature summaries extracted from (NOAA, 2012) for stations in the ten administrative divisions (figure 10) were converted into a table of monthly averages (^{o}C) for the corresponding divisions of Malaysia studied in this research. The monthly temperature averages of 36 months prior to harvest calculated for the ten divisions and the corresponding monthly oil palm yield for these individual divisions were analysed to determine the lag effects of the temperature on oil palm yield across Malaysia at this scale. Further details on the data could be obtained from (Shanmuganathan S., Narayanan, Mohammed, Ibrahim, & Khalid, 2014).

The results of ARIMAX model and data mining techniques obtained for 1) long term East and West Malaysian yield data with monthly temperature (36) and precipitation (36) anomalies, and 2) short term yield data for Malaysia's ten administrative divisions with 36 monthly average temperatures, are presented in the next section.

RESULTS AND DISCUSSIONS

The results of the long and short term time series data analysis and mining using oil palm yield (FFB tons/ha/month) as dependent and lag variables (monthly anomalies i.e., temperature and precipitation)/ monthly average temperatures of 36 months prior to each monthly harvest) as independent variables show the significant patterns in the effects of climate change on monthly oil palm yield. Furthermore, the results demonstrate how emerging data science techniques could be used to enhance time series analysis for understanding complex crop-climate-yield interactions and yield forecasting to inform regional/ local administrative management as well as policy making personnel (on the use of natural resources, such as land, water) at these scales.

Trends in Long Term Time Series Data (Oil Palm Yield)

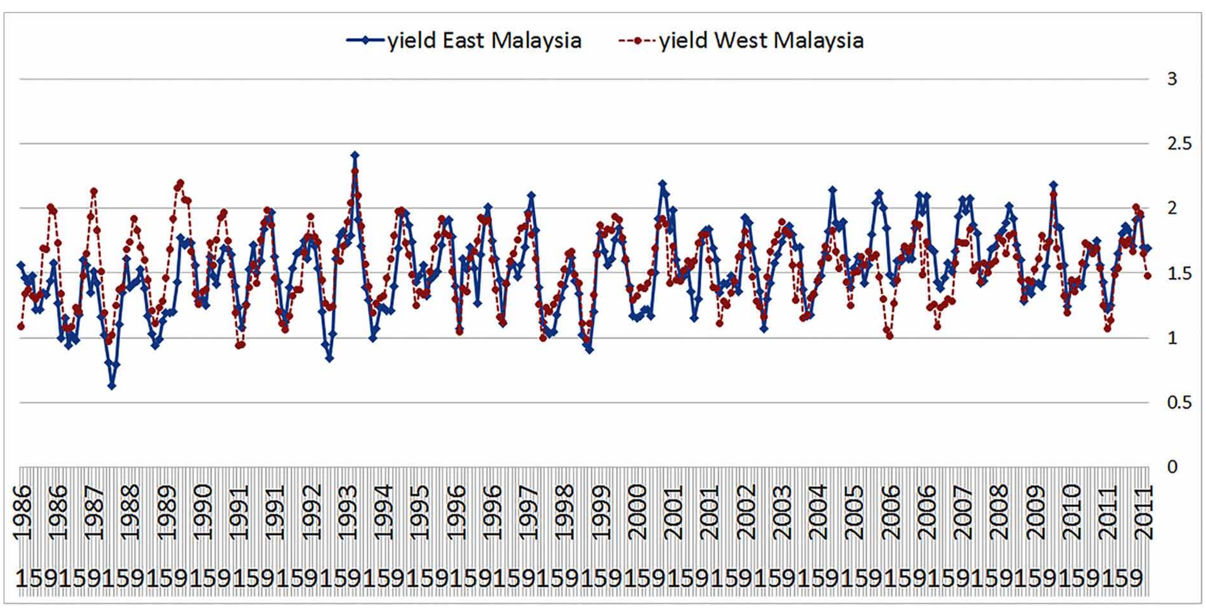
An ordinary graph of the monthly oil palm yield data (January 1986 to December 2011) plotted against time, shows the variability in monthly yield of West (Peninsular) and East (Borneo or Sabah and Sarawak) Malaysia. The monthly oil palm yield of West Malaysia that was high between1986-1990 has equalled out in the late 1990s and then observed to be below that of East (figure 1). The monthly yield seem to have peaked in September - November months for both East and West Malaysia throughout the study period. Meanwhile, the troughs can be observed in the month of February mostly.

ARIMAX Model Results of Long Term Time Series Data

West Malaysia

ARIMAX (1,0,2)(1,1,1), 2nd order model with 7 independent variables (table 3) was found to be the best fit for the long term monthly on oil palm yield in West (Peninsular) Malaysia for the time period studied (January 1986 -December2011). With a *p-value* 0.067, the model is adequate, with R^2 .725, it represents 72.5% of the data (table 2). The independent variable data (monthly anomalies in temperature and precipitation) has been already differenced hence a 2nd order model was needed to identify the difference in this already differenced anomaly data. In the ACFs of West Malaysia ARIMAX(1,0,2)(1,1,1) model (figure 2), the residuals with peaks at 12 and 6 month die off and this can be related to the annual peaks observed in the yield graph (figure 1).

Figure 1. Graph showing the trends in oil palm monthly yield (FFB tons/ha) from East (Sarawak and Sabah /yield ss) and West (Peninsular/ yield pm) Malaysia between January 1986 to December 2011. Key: pm; Peninsular/ West, ss; Sarawak and Sabah/ East/ Borneo Malaysia)



Of the 72 variables used (36 monthly temperature and 36 monthly rainfall anomalies prior to harvest), 7 predictors were found to be significant at 95% (table 3) for this ARIMAX(1,0,2)(1,1,1) model. Among the 36 monthly temperature anomalies 1, 12 and 25 months prior to harvest were found to be significant. Meanwhile, of the 36 precipitation anomalies, 33, 12, 10 and 9 months prior to harvest were also found to be the predictors for this model. These months (prior to harvest) relate to fruit maturation ripening (1 between 6-0), flower development / flower opening and anthesis (12 between 22-12/12-5), and finally flower sex differentiation/ bunch formation (25 between 33-18) stages (table 1) respectively. The rationale behind this is that less than ideal weather conditions during flower development, flowering and fruit ripening (later stages of the oil palm production cycle) have led to reductions in fruit set and weight, both reflecting in low yields (FFB)

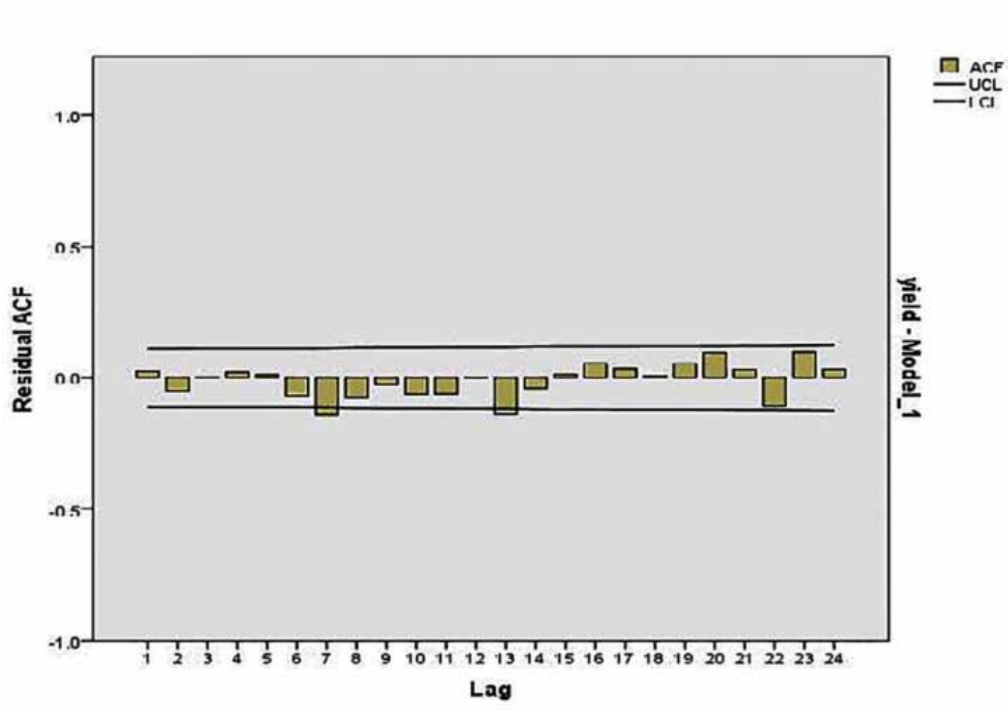
Table 2. ARIMAX(1,0,2)(1,1,1) model statistics for West (Peninsular) Malaysia's monthly oil palm yield data (1986-2011)

Model	Yield-Model_1	
Number of Predictors		72
Model Fit statistics	Stationary R-squared	0.725
	RMSE	0.134
	Normalized BIC	-2.55
Ljung-Box Q(18)	Statistics	21.292
	DF	13
	Sig.	**0.067**
Number of Outliers		0

Table 3. Independent variables of ARIMAX(1,0,2) (1,1,1) for West (peninsular) Malaysia's monthly oil palm yield (1986-2011)

ARIMA Model Parameters			Estimate	SE	t	Sig.
	AR	Lag 1	0.503	0.136	3.686	0
	MA	Lag 1	0.370	0.132	2.79	0.006
		Lag 2	-0.358	0.081	-4.437	0
	AR, Seasonal	Lag 1	0.029	0.101	0.284	0.776
	Seasonal Difference		1			
	MA, Seasonal	Lag 1	0.993	1.142	0.869	0.386
T_25	Numerator	Lag 0	-0.061	0.023	-2.626	0.009
T_12	Numerator	Lag 0	0.059	0.023	2.548	0.012
T_1	Numerator	Lag 0	0.045	0.021	2.169	0.031
PP_33	Numerator	Lag 0	0.000	0	-2.387	0.018
PP_32	Numerator	Lag 0	0.000	0	-0.716	0.475
PP_12	Numerator	Lag 0	0.000	0	2.149	0.033
PP_10	Numerator	Lag 0	0.000	0	2.07	0.04
PP_9	Numerator	Lag 0	0.000	0	2.574	0.011

Figure 2. ACFs of West Malaysia ARIMAX(1,0,2)(1,1,1) model, residuals with peaks at month 12 and 6 die off



in 1-12/22 months later. Similarly, not so ideal weather during frond emergence and flower sex differentiation (leading to low female/male ratios) and bunch formation (initial – mid stages) have led to reductions in number of fruits/bunch formed, again resulting in less fruits/ bunches (low yield /FFB) reflected in 25 months later.

East Malaysia

For East (Borneo) Malaysia ARIMAX(2,0,0)(1,1,1) model with 5 independent variables was found to be the best fit for the long term monthly time series data on palm oil yield in this region. Here again a 2nd order model was the best fit for the data over this time period the reason being independent climate anomaly data has been already normalised and needed a 2nd order as explained for West Malaysia. With a *p-value* 0.089, the model is adequate and with R^2 .785, it represents 78% of the data (table 4). The predictors for this model were, precipitation anomalies 33, 11, 10, 6 and 5 months prior to harvest (table 5), more or less same as those affecting the West, the stages affected

Table 4. ARIMAX(2,0,0)(1,1,1) model statistics for East (Borneo) Malaysia's monthly oil palm yield data (1986-2011)

Model	Yield-Model_1	
Number of Predictors		72
Model Fit statistics	Stationary R-squared	0.785
	RMSE	0.142
	Normalized BIC	-2.441
Ljung-Box Q(18)	Statistics	21.522
	DF	14
	Sig.	0.089
Number of Outliers		0

Table 5. Independent variables of ARIMAX(2,0,0)x(1,1,1) for East (Borneo) Malaysia's monthly oil palm yield (1986-2011)

ARIMA Model Parameters			Estimate	SE	t	Sig.
yield	Constant		-0.167	0.084	-1.98	0.048
	AR	Lag 1	0.847	0.068	12.54	0
		Lag 2	-0.123	0.068	-1.79	0.074
	AR, Seasonal	Lag 1	0.125	0.092	1.367	0.173
	Seasonal Difference		1			
	MA, Seasonal	Lag 1	0.991	0.977	1.015	0.311
pp_23	Numerator	Lag 0	0	7.49E-05	-2.04	0.042
pp_11	Numerator	Lag 0	0	6.68E-05	2.816	0.005
pp_10	Numerator	Lag 0	0	6.66E-05	2.571	0.011
pp_6	Numerator	Lag 0	0	6.67E-05	-3.05	0.003
pp_5	Numerator	Lag 0	0	6.66E-05	-2.85	0.005

Figure 3. ACFs of East Malaysia ARIMAX(2,0,0)(1,1,1) model, residuals with peaks at month 12 and 6 die off

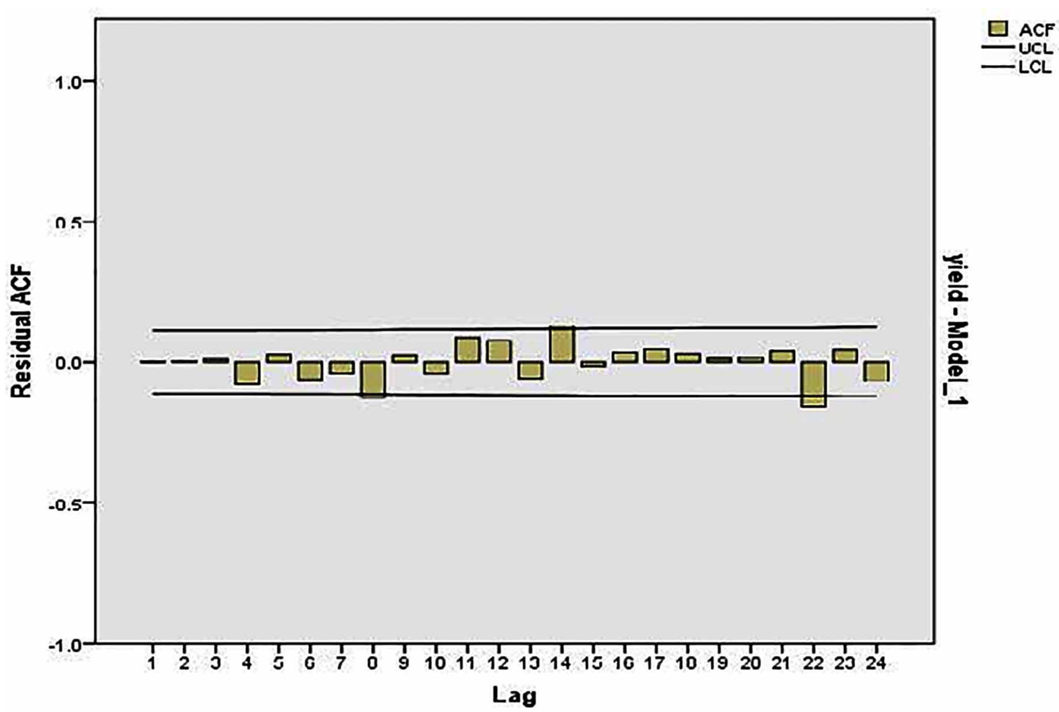
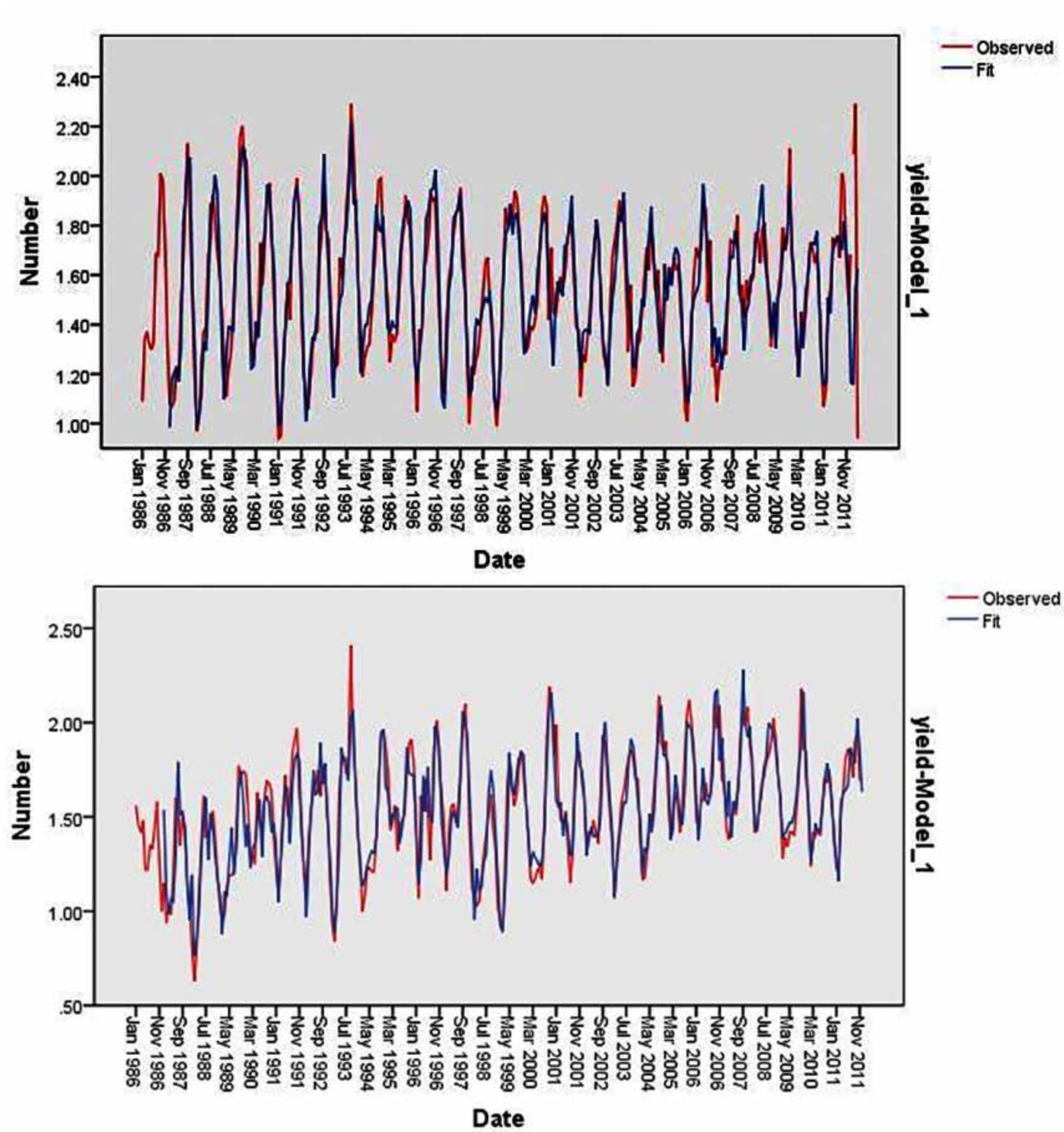


Figure 4. West (above: Peninsular ARIMAX(1,,0,2)(1,1,1) and East (below: Borneo ARIMAX (0,0,2) (1,1,1,) Malaysia time series real and ARIMAX model predictions of monthly yield



being fruit maturing, flowering and flower sex differentiation. However, not a single temperature anomaly was found to be in the significant predictors at the 95% confidence interval. In the ACFs of East Malaysia ARIMAX(2,0,0)(1,1,1) model (figure 3), the residuals with peaks at 12 and 6 month die off and this can be related to the annual peaks observed in the yield graph (figure 1).

The different trends in the oil palm monthly yields and ARIMAX model predictions of West and East Malaysia could be observed in figure 4. Time series plots of West and East Malaysian monthly oil palm yields (figure 1) show the difference in the periodicity and cyclicity in the data. The long term time series ARIMAX models show that the climate change effects of West and East

Malaysia on oil palm yield have similarities and dissimilarities as well. This suggests that the climate effects on the oil palm tree phenology in the two regions that lie on either side of South China Sea as varying which reiterates what was concluded in (Shanmuganathan & Narayanan, 2012). Even though both regions have been affected at the same stages in the production cycle, based on the respective ARIMAX model results, oil palm yield in West has been affected by temperature and precipitation anomalies whereas, East yield has been affected only by precipitation anomalies. Interestingly, the same monthly precipitation anomalies prior to harvest have shown lagged effects on the yield, the months being for West (33, 12, 10 and 9), and for East (33, 11, 10, 6 and 5)

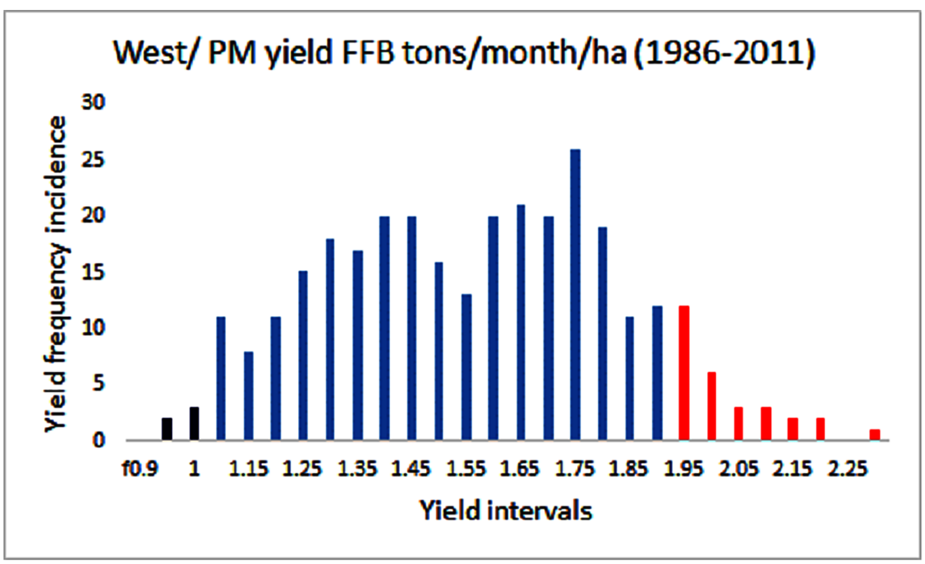
Data Mining Results of Long Term Time Series Yield

The data used in the above ARIMA modelling of West and East Malaysia's yield classes (figures. 4 and 7), 72 lag variables, 36 temperature and 36 precipitation anomalies obtained for the 36 months prior to harvest were analysed using data mining techniques (WEKA software modules JRip and J48) and the results are discussed in this section.

ARIMAX and Data Mining Results of Long Term Time Series Yield (West Malaysia)

Of the West Malaysia ARIMAX (1,0,2)(1,1,1) model predictors (independent variables), lag

Figure 5. A) Yield classes created for analysis using data mining techniques and histogram showing the West (Peninsular) Malaysia's monthly oil palm yield distribution over the 25 year period (1986-2011) B) ssociation rules (WEKA JRip) revealing the months and anomalies (temperature and /or precipitation) that are significant in determining the monthly oil palm yield in West (Peninsular) Malaysia




```
JRIP rules:
===========
1. (T_22 <= -0.28) => yield class = low (7.0/3.0)
2. (T_23 <= -0.28) and (T_34 <= 0.31) => yield class = low (4.0/0.0)
3. (T_6 <= 0.18) and (T_8 <= 0.13) and (T_3 >= 0.3) => yield class = high (7.0/0.0)
4. (PP_22 >= 177.28) and (T_33 <= 0.44) => yield class = high (3.0/0.0)
   => Yield class = med (291.0/16.0)
```

Figure 6. Decision tree rules (WEKA J48) revealing the anomalies (in temperature/ precipitation) and the months that contribute to oil palm yield either favourable or adversely in West (Peninsular) Malaysia

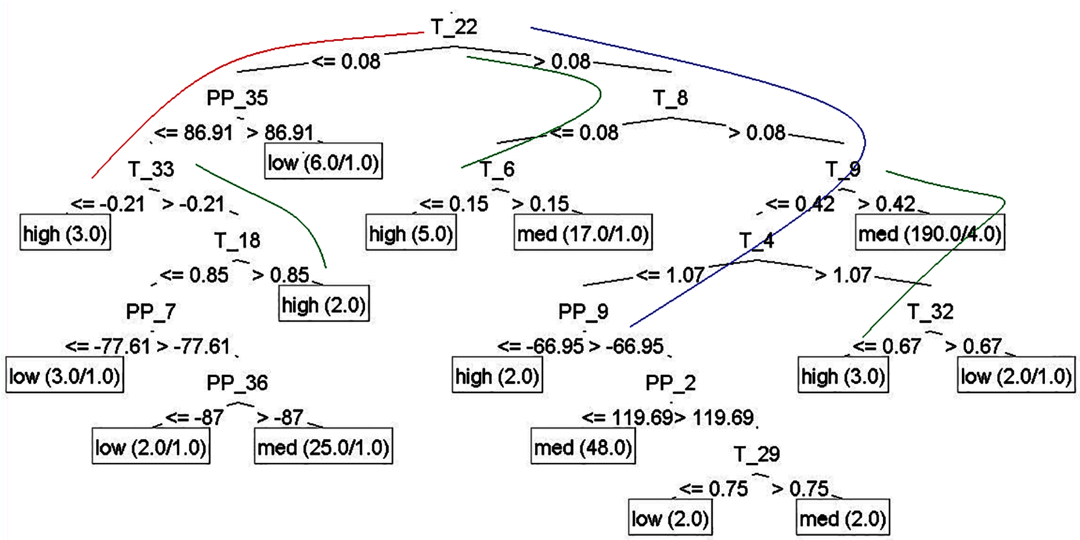
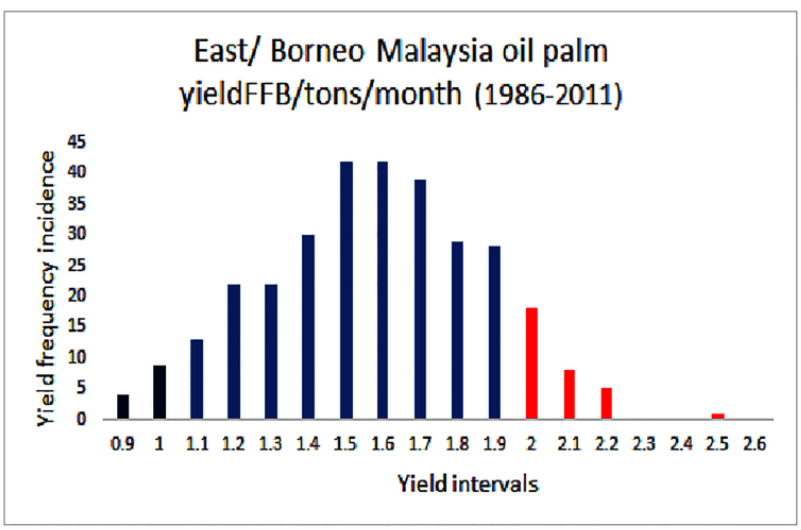


Figure 7. Yield classes created for analysis using data mining techniques and histogram showing the East (Borneo/ Sabah and Sarawak) Malaysia's monthly yield distribution over the 25 year period (1986-2011)



variables T_25, T_12 and T_1 (temperature anomalies of 25, 12 and 1 month/s) and precipitation anomalies of PP_33, PP_32, PP_12, PP_10 and PP_9 (month/s prior to harvest) were found to be significant at 95% confidence interval. Among these significant ARIMA model predictors, lag variable PP_33 has been supplemented by WEKA's JRip and J48 association rules with further details on the weather conditions relating to the lag variable and they are:

- In JRip rule No. 4 (figure 5) temperature anomaly of month 33 (T_33) prior to harvest <= 0.44 ^{o}C along with precipitation during 22 months prior to harvest PP_22 >=177.28 mm is found to be one of the conditions for high yield (>=1.95 t/h/m). This means effects of low temperature during the frond emergence and bunch formation time could be compensated for by higher rainfall during the frond emission stage. The conditions have been met in 3 instances without no exceptions during the time period studied (1986-2011). Hence, this JRip rule gives additional information on the temperature for the lag variable PP_33 in West Malaysia's ARIMAX model, required for achieving high yield.
- Among the J48 decision tree rules (leftmost path in red of (figure 6), temperature anomaly 33 months prior to harvest (T_33) should be <= -0.21 ^{o}C for high yield. In addition, if T_33 was >= -0.21 ^{o}C, then T_18 should be >0.85 ^{o}C for getting high yield, the conditions have been met two occasions without any exceptions.
- J48 decision tree rules (figure 6), lower than normal precipitation anomaly during 9 months prior to harvest is among the final requirements for high yield (blue line in figure 6).

From the above first two points (common predictors of ARIMAX and data mining models), it could be established that lag variables, temperature at T_22 and T_33 (22 and 33 months prior to harvest relating to frond emergence (initial) and flower sex differentiation (bunch formation) stages) of the oil palm production cycle are the very important predictors/ determinants of the yield. The data mining rules give the precise temperature and rainfall anomaly ranges along with additional/ compensating conditions if the original high yield conditions were not met (shown in different lines in figure 6). For instance, the additional condition for T_33<= 0.44 ^{o}C is PP_22 >=177.28 mm for high yield (JRip rule 4 in figure 5). Meanwhile, if T_33 was <= -0.21 ^{o}C subsequent conditions T_22<0.08 ^{o}C and earlier PP_35 <=86.91 mm are required for high yield (as per J48 decision tree path indicated in red line in figure 6). If the temperature of T_33 was >= -0.21 ^{o}C then T_18 should be >0.85 ^{o}C to produce high yield.

It then appears that the lag variables T_33 and T_22 (33 and 22 months prior to harvest period) related to the frond emergence and sex determination of the oil palm tree fruit production cycle (table. 1), are the major determinants and their effects reflected in yield not immediately but in 22 months later. It is when based on data mining results compensating conditions at T_22 (22 months prior to harvest) were not met either (J48 tree paths for high yield in figure 6). This is almost same as the high end of the range (high temperatures reflected in yield in 10-24 months later) used in (Amanah investment bank berhad, 2014) for explaining yield losses as lagged in major oil palm plantations.

As far as the low end of the above 10-24 month range is concerned, JRip rule no. 3 (figure 5) gives further details on the weather conditions for high yield. Lag variables T_6 <= 0.18 ^{o}C, T_8 <=0.13 ^{o}C and T_3 >=0.3 ^{o}C (monthly temperature anomalies at 6, 8 and 3 months prior to harvest) have led to high yield with 7 instances without any exceptions. Here again, the weather conditions 8-3 months prior to harvest relate to flower opening (and anthesis) and fruit ripening stages. High or low temperatures during the 8 months prior to harvest (fruit ripening stage) will be reflected in the yield 8 months later, at the lower end of the lag period 10-24 months stated in (Amanah investment bank berhad, 2014). High temperature during flower opening could not be compensated for during the fruit ripening stage. Furthermore, based on above interpretations of JRip association rules 1 and 2 (figure 5) very low and very high monthly average temperatures during this initial stage have led to low yield approximately 22-24 months later.

Data Mining Results of Long Term Yield Data (East Malaysia)

Based on JRip association rules, anomalies for monthly temperatures during month 32, 31, 27 and 2 and for precipitation at 28, 26 and 13 prior to harvest are the significant independent determinants for high yield (>=2 t/ha/m) in East (Borneo) Malaysia (figures 8 and 9). The time period relating to the oil palm production cycle stages are; frond emergence, sex differentiation or bunch formation and flower development respectively. Hence, like West Malaysia, in the East as well low rainfall and low temperatures in months relating to these stages have led to low yield.

In particular, low deviations from mean in temperature (anomalies) during 36 and 23 (frond emergence and sex differentiation) as well as drought (precipitation <=-209) during 2 months prior to harvest (fruit maturing) as in JRip rule 4 (figure 9) had led to low yield in East Malaysia. This also indicates that low temperatures in the very beginning/ frond emergence and very end/ fruit maturity of the fruit production cycle had led to low yield.

ARIMAX and Data Mining Results of East Malaysia

As per decision tree rules (WEKA J48 algorithm) of all the precipitation anomalies, 34, 32, 31, 23 and 3 months prior to harvest are the months that ultimately determine the high yield in East (Borneo) Malaysia (figure 9). The ARIMAX (0,0,2)(1,1,1) model for East Malaysia consists of precipitation anomalies alone as determinants, the months being 33, 11, 10, 6 and 5 months prior to harvest. The precipitation anomaly at 34-31 months prior to harvest seems to be significant in both models; this month falls in the frond emergence and early sex differentiation stages of the oil palm fruit production cycle (table 1). 10 and 6-5 months prior to harvest (of the ARIMAX model) are the stages at which flower opening and anthesis occur. Hence, from the results of ARIMAX, the lagged effects on yield reflected in 33 months and any damage caused by drought at this frond emergence stage cannot be compensated for. However, based on JRip and J48 association and decision tree rules (figures 8 and 9), damage caused by lower precipitation or drought during frond emergence has been compensated for by higher precipitation and higher temperature (ideal conditions for increased photosynthesis) during the frond emission stage.

Trends in Short Term Yield Data (Monthly Oil Palm Yield)

The results of short term (2007-2011) monthly yield for the ten administrative divisions of Malaysia (figure 10) are discussed in this section.

The monthly yields of the ten divisions studied (figure 10) show common peaks (October-November) and troughs (December-February) over the five year period (January 2007 to December 2011). There is a peak observed across all the divisions in October 2009, likewise a trough can be observed in January 2009. However, occasionally there are some deviations from the common trend, for example, Penang showed a steep downward trend between June-December 2010 whereas, the other divisions showed a dip and a slight peak within the same period. It is also obvious that Malacca has the highest yield rate while Kelantan got the

Figure 8. Decision tree rules (WEKA J48 output) reveal the monthly anomalies (in temperature/ precipitation) that contributed to oil palm yield either favourably or adversely in East/ Borneo Malaysia

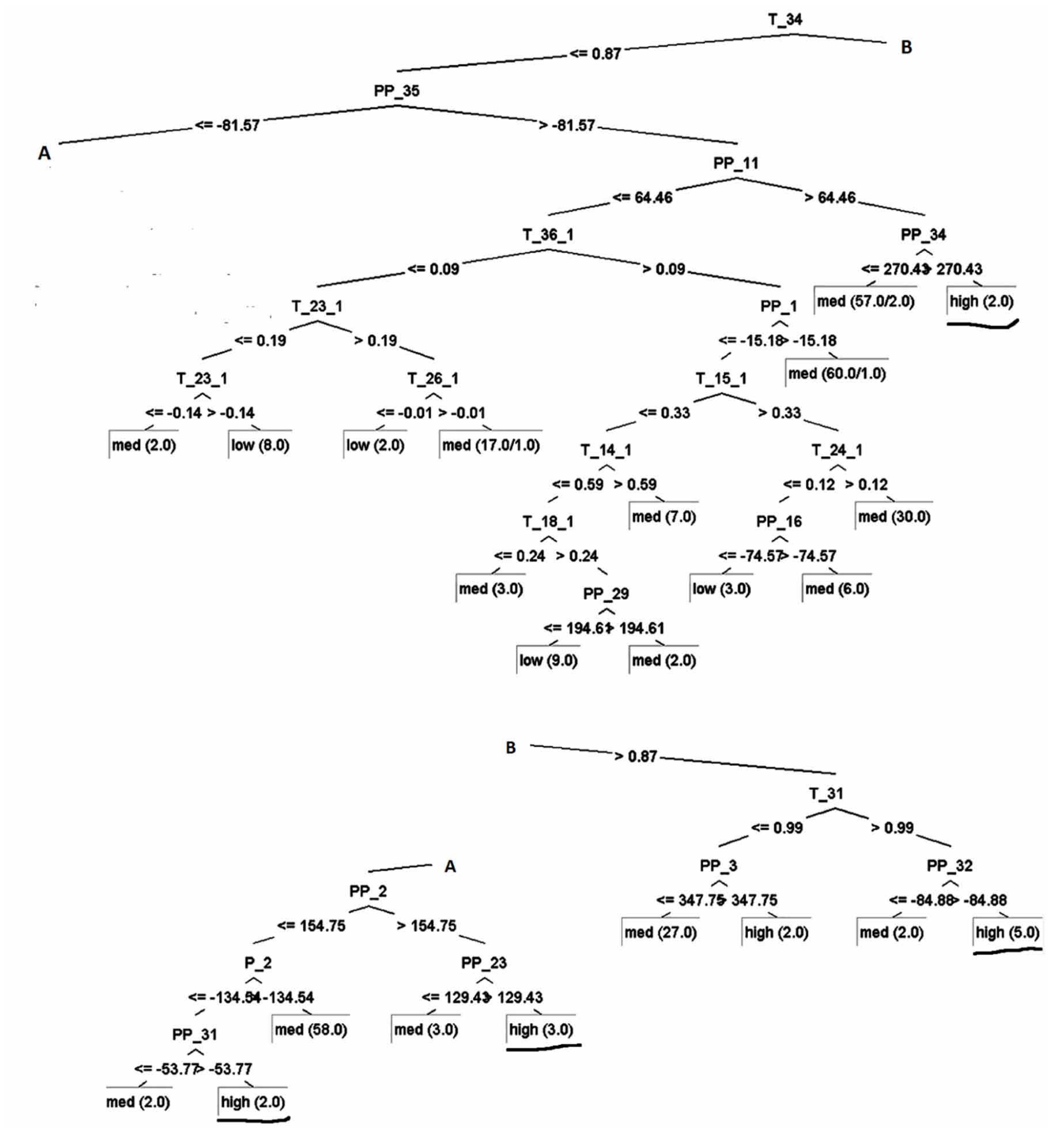


Figure 9. Association rules (WEKA JRip) revealing the months and anomalies (temperature and /or precipitation) that are significant in determining the monthly oil palm yield in Borneo Malaysia

```
JRIP rules:
===========

1. (T_27 >= 0.57) and (PP_28 >= 104.64) and (PP_13 >= 76.61) => yield class = high (8.0/2.0)
2. (T_31 >= 0.94) and (PP_26 >= 142.64) => yield class=high (3.0/0.0)
3. (T_2 >= 1.11) and (T_32 >= 0.69) => yield class = high (3.0/0.0)
4. (T_36 <= 0.09) and (T_23 <= 0.19) => yield class = low (13.0/4.0)
5. (PP_2 <= -209.19) => yield class = low (4.0/1.0)
   => Yield class = med (281.0/16.0)
```

Figure 10. Top: Graph showing the seasonal and cyclic trends in the monthly oil palm yield (FFB T/ha) harvested in ten of thirteen administrative regions of Malaysia through January 2007 to December 2011. The peaks and troughs over this five year period show the common and unusual trends across the divisions studied. Bottom: Map showing the corresponding ten administrative divisions of Malaysia on the above yield graph

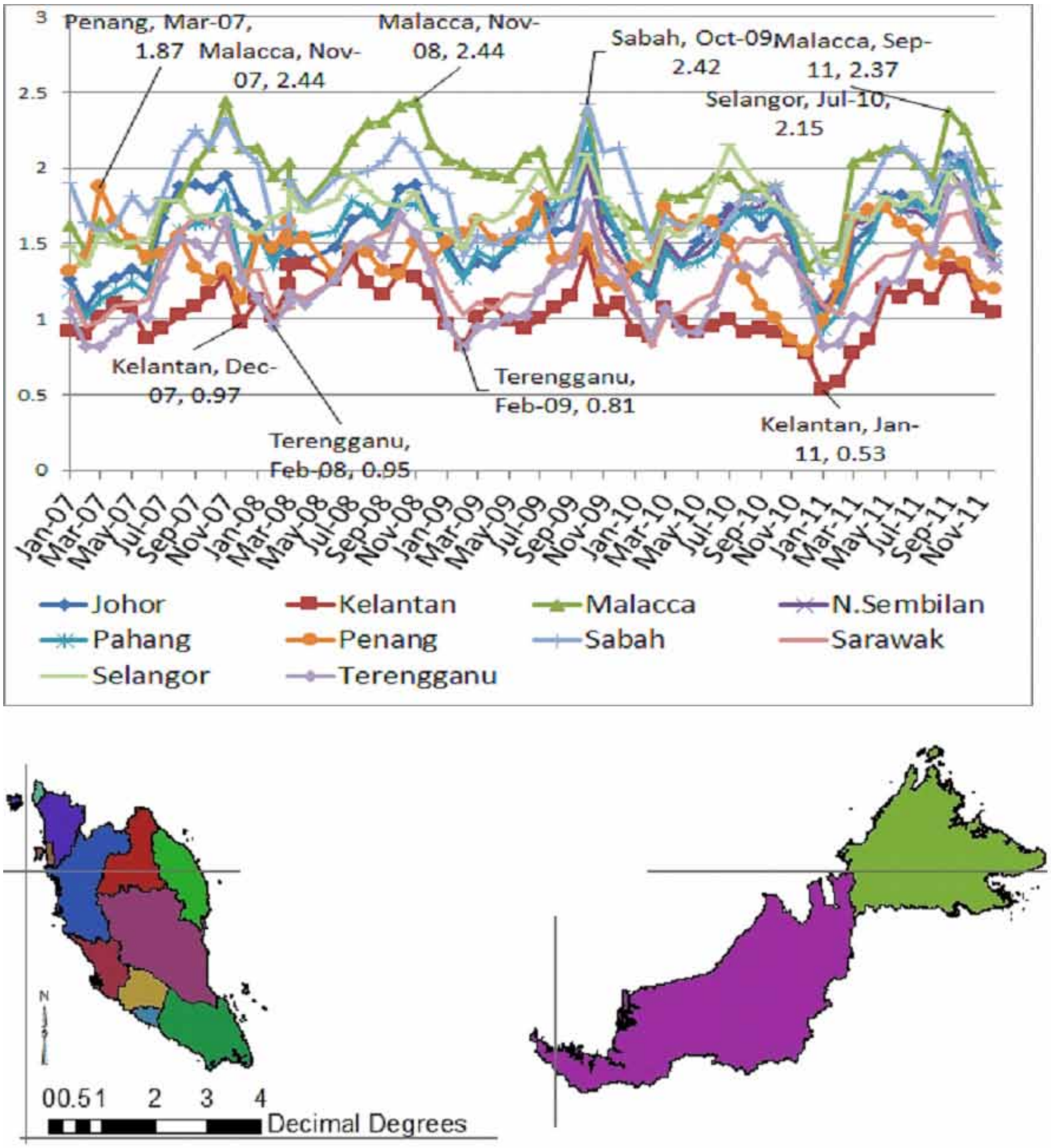


Table 6. ARIMA model output of different admin. divisions of Malaysia show the models and parameters for monthly oil palm yield data (2007-2009)

ARIMA Model Parameters				Estimate	SE	t	Sig.
Kelantan ARIMA(0,0,3)(0,1,1)	No Transformation	MA	Lag 1	-0.619	0.147	-4.215	0
			Lag 2	-0.633	0.161	-3.931	0
			Lag 3	-0.348	0.164	-2.129	0.039
		Seasonal Difference		1			
		MA, Seasonal	Lag 1	0.601	0.268	2.245	0.03
*Pahang ARIMA(1,0,0)(0,1,0)	Natural Logarithm	AR	Lag 1	0.742	0.097	7.625	0
		Seasonal Difference		1			
Sabah ARIMA(0,0,2)(1,0,0)	No Transformation	Constant		1.845	0.069	26.86	0
		MA	Lag 1	-0.79	0.129	-6.141	0
			Lag 2	-0.414	0.128	-3.23	0.002
		AR, Seasonal	Lag 1	0.424	0.133	3.193	0.002
*Sarawak ARIMA(1,0,0)(0,1,0)	No Transformation	AR	Lag 1	0.631	0.115	5.484	0
		Seasonal Difference		1			
***Johor ARIMA(1,0,0)(1,0,0)	Natural Logarithm	Constant		0.432	0.091	4.762	0
		AR	Lag 1	0.736	0.087	8.451	0
		AR, Seasonal	Lag 1	0.646	0.108	6.003	0
*Selangor ARIMA(1,0,0)(0,1,0)	No Transformation	AR	Lag 1	0.512	0.125	4.099	0
		Seasonal Difference		1			
**Terengganu ARIMA(1,0,0)(1,1,0)	Natural Logarithm	AR	Lag 1	0.557	0.124	4.48	0
		AR, Seasonal	Lag 1	-0.537	0.152	-3.523	0.001
		Seasonal Difference		1			
****Penang ARIMA(1,0,0)(0,1,0)	No Transformation	AR	Lag 1	0.722	0.113	6.359	0
		Seasonal Difference		1			
	No Transformation	Delay		5			
		Numerator	Lag 0	0.122	0.05	2.43	0.02

lowest among the studied divisions throughout the study period.

ARIMA Model Results of Short Term Time Series Data

ARIMA models constructed for modelling and understanding the climate change effects on oil palm yield using short term yield data in the ten administrative divisions of Malaysia with selected monthly average temperature averages found to be significant in determining monthly divisional oil palm yield through research in (Shanmuganathan S., Narayanan, Mohammed, Ibrahim, & Khalid, 2014), are discussed in this section.

Of the best fit ARIMAX models constructed for the respective divisional monthly oil palm yield (table 7), Pahang ARIMAX(1,0,0)(0,1,0) got the highest significance value 0.938, the second highest 0.92 by Terengganu ARIMAX(1,0,0)(1,1,0) model. The rest of the models as well have *p-values* > 0.05, adequate to represent the data

Table 7. ARIMA model statistics output of different admin. Divisions of Malaysia show the models and parameters for monthly oil palm yield data (2007-2009). Prs: Predictors

Model	No. of Prs	Model Fit Statistics			Ljung-Box Q(18)			No. Outliers
		Stationary R-Squared	RMSE	Normalized BIC	Statistics	DF	Sig.	
Kelantan ARIMA(0,0,3)(0,1,1)	0	.670	.150	-3.476	19.156	14	0.159	0
Pahang ARIMA(1,0,0)(0,1,0)	0	0.467	0.181	-3.336	9.058	17	0.938	0
Sabah ARIMA(0,0,2)(1,0,0)	0	0.6	0.163	-3.353	18.92	15	0.217	0
Sarawak ARIMA(1,0,0)(0,1,0)	0	0.363	0.109	-4.358	21.109	17	0.221	0
Johor ARIMA(1,0,0)(1,0,0)	0	0.655	0.152	-3.559	11.456	16	0.781	0
Selangor ARIMA(1,0,0)(0,1,0)	0	0.249	0.136	-3.909	20.728	17	0.239	0
Terengganu ARIMA(1,0,0)(1,1,0)	0	0.469	0.151	-3.622	8.841	16	0.92	0
Penang ARIMA(1,0,0)(0,1,0)	1	0.559	0.152	-3.588	14.829	17	0.608	0

based on Jenkins and box method. The RMSE and Normalised BIC values are <0.2 and within the 3 - -4 range respectively. As far as R^2 values are concerned, Kelantan ARIMAX(0,0,3)(0,1,1) has the highest 0.670 meaning the model represents 67% of the data. The lowest of all, Sarawak ARIMAX(1,0,0)(0,1,0) with R^2 value 0.363 represents 36% of the data.

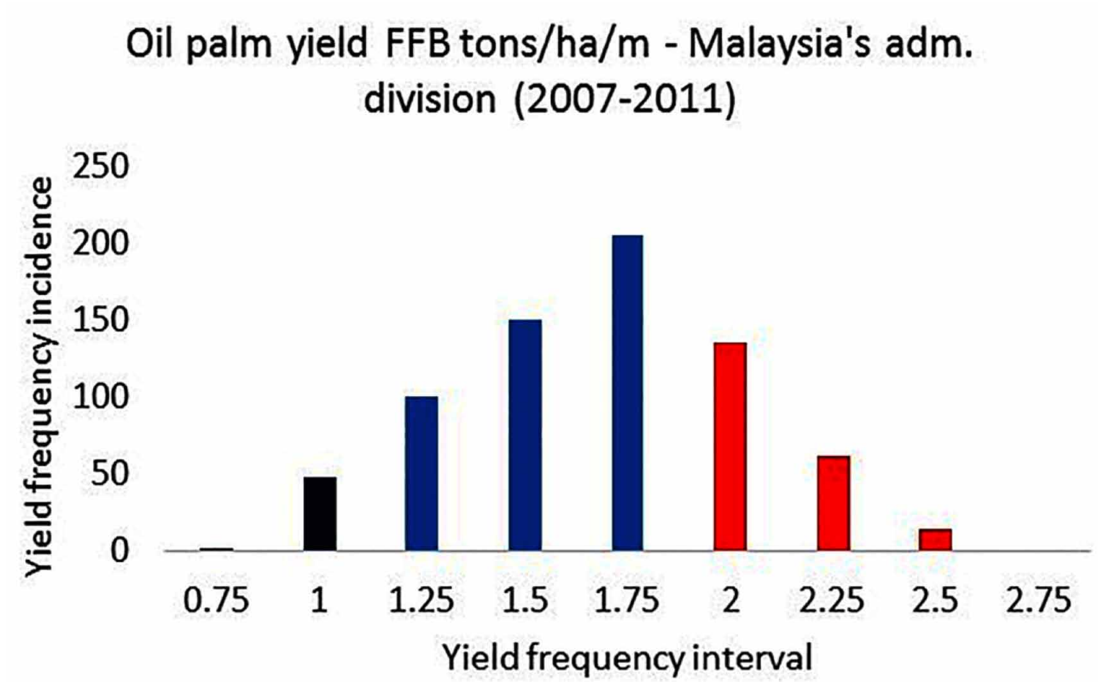
From the model parameter statistics (tables 6 and 7), Pahang ARIMAX(1,0,0)(0,1,0), Sarawak ARIMA(X1,0,0)(0,1,0), Selangor ARIMAX(1,0,0)(0,1,0), Terengganu ARIMAX(1,0,0)(1,1,0), Penang ARIMAX(1,0,0)(0,1,0) consist of estimated AR seasonal difference of 1. However, in Terengganu in addition to the seasonal difference, the model consists of an estimated AR seasonal lag 1. Meanwhile, Penang exhibits an additional estimated delay of 5. This explains the deviation (lag/delay) exhibited by Penang divisional monthly yield also seen in yield graph (figure 10).

Johor ARIMAX(1,0,0)(1,0,0) consists of AR lag (1), AR seasonal lag (1) and an estimated constant 0.432. Kelantan ARIMAX(0,0,3)(0,1,1) and Sabah ARIMAX(0,0,2)(1,0,0) models exhibit MA lag 1-3 and 1-2 respectively. In addition, Kelantan has MA seasonal lag (1) and MA difference of an estimated 1. Meanwhile, Sabah ARIMAX(0,0,2)(1,0,0) consists of AR seasonal lag (1). An ARIMAX model for Malacca could not be constructed to adequately represent the five year, monthly yield data. The ARIMAX models so far constructed for the divisional monthly yield, provided further insight into the highly varying complex nature and operations of external factors i.e., climate, environmental, and internal (feedback mechanisms), that are described as determinants of oil palm yield throughout the tree productive cycle across the different administrative divisions of Malaysia as concluded in (Shanmuganathan S., Narayanan, Mohammed, Ibrahim, & Khalid, 2014).

Short Term Time Series Yield Data Mining Results

The WEKA (JRip and J48 data mining module) results of the short term time series data provide details of the monthly average temperature/s that had affected the yield during January 2007- December 2011 in the respective divisions.

Figure 11. Yield classes created for analysis using data mining techniques and histogram showing the data distribution of monthly oil palm yield in the admin. Divisions of Malaysia during 2007-2011



The following are the interpretations arrived at from the decision tree rules (WEKA J48) generated for the short term time series yield data (figure 12):

- Johor yield is affected by the temperature in -4 and -13 months (prior to harvest). The monthly average temperature >27.11 ^{o}C at month -4 and <= 26.46 ^{o}C and at month -13 (prior to harvest) had led to high yield (>=2 ton/ha/m). This indicates the significance of the temperature during the later stages (flower development and fruit maturation) of oil palm fruit production cycle (table 1). Hence, based on the rules the lag time between ideal weather and high yield is 4-13 months for Johor.
- Malacca's yield has several stages that can compensate for any damage caused by unfavourable weather conditions at critical stages of the oil palm production cycles. For example, month -29 (prior to harvest relating to initial and bunch formation stages) monthly average temperature <= 27.42 ^{o}C damage could be recuperated by <= 26.8 ^{o}C: high (4.1-met at 4 instances and with 1 exception) at -18 months (prior to harvest) average temperature or tolerated if months -33 (prior to harvest) was >28.37 ^{o}C: high (2.0). Lag time between ideal weather and high yield is 29-33 months for Malacca.
- For Pahang month 9 (prior to harvest) temperature (flower opening and anthesis) is the only determinant for yield with a lag time of 9 months between ideal weather and high yield.
- For Sabah, temperatures during the early stages of the productive cycle -31 to -15 months (prior to harvest) at frond emission, flower sex differentiation through to flower development and abortion stages appear to be critical. Low monthly temperature averages during the -15 - -31 months (prior to

Figure 12. Association rules (WEKA J48 algorithm) revealing the monthly temperature/s that are significant in determining the monthly oil palm yield in the Malaysia's admin. Divisions during 2007-2011

```
J48 pruned tree
------------------
D = Johor
|  T-4 <= 27.11: med (52.0)
|  T-4 > 27.11
|  |  T-13 <= 26.46: high (3.0)
|  |  T-13 > 26.46: med (5.0)
D = Kelantan
|  T-18 <= 26.17: low (5.0)
|  T-18 > 26.17
|  |  T-20 <= 27.67: med (40.0/8.0)
|  |  T-20 > 27.67
|  |  |  T-9 <= 27.27: med (4.0)
|  |  |  T-9 > 27.27: low (11.0)
D = Malacca
|  T-29 <= 27.42
|  |  T-18 <= 26.8: high (4.0/1.0)
|  |  T-18 > 26.8
|  |  |  T-33 <= 28.37: med (21.0)
|  |  |  T-33 > 28.37: high (2.0)
|  T-29 > 27.42
|  |  T-22 <= 27.02: high (9.0)
|  |  T-22 > 27.02
|  |  |  T-6 <= 27.46
|  |  |  |  T-12 <= 27.48: high (8.0)
|  |  |  |  T-12 > 27.48
|  |  |  |  |  T-5 <= 27.8: med (3.0)
|  |  |  |  |  T-5 > 27.8: high (2.0)
|  |  |  T-6 > 27.46: med (11.0/1.0)
D = Sembilan: med (30.0/1.0)
D = Pahang
|  T-9 <= 25.51: high (4.0/1.0)
|  T-9 > 25.51: med (56.0/1.0)
D = Penang
|  T-7 <= 28.03: med (57.0)
|  T-7 > 28.03: low (3.0)
```

```
J48 pruned tree (contd.)
D = Sabah
|  T-27 <= 26.83
|  |  T-17 <= 27.25
|  |  |  T-15 <= 26.57: med (29.0)
|  |  |  T-15 > 26.57
|  |  |  |  T-32 <= 26.57
|  |  |  |  |  T-21 <= 26.56: med (9.0)
|  |  |  |  |  T-21 > 26.56: high (3.0/1.0)
|  |  |  |  T-32 > 26.57: high (2.0)
|  |  T-17 > 27.25: high (2.0)
|  T-27 > 26.83
|  |  T-31 <= 26.08: med (4.0)
|  |  T-31 > 26.08: high (11.0) ****
D = Sarawak
|  T-33 <= 28.12: med (53.0)
|  T-33 > 28.12 ****
|  |  T-34 <= 27.88: med (3.0)
|  |  T-34 > 27.88: low (4.0/1.0) ****
D = Selangor
|  T-4 <= 28.35: med (56.0)
|  T-4 > 28.35
|  |  T-36 <= 27.43: high (2.0)
|  |  T-36 > 27.43: med (2.0)
D = Terengganu
|  T-26 <= 27.19
|  |  T-19 <= 27.35: med (3.0)
|  |  T-19 > 27.35
|  |  |  T-15 <= 27.09: low (9.0)
|  |  |  T-15 > 27.09
|  |  |  |  T-24 <= 26.75: low (3.0)
|  |  |  |  T-24 > 26.75: med (4.0)
|  T-26 > 27.19
|  |  T-2 <= 27.19: low (3.0/1.0)
|  |  T-2 > 27.19: med (38.0)
```

harvest) and high averages during -21- -15 months (prior to harvest) have led to high yield in this administrative division, here again with a lag time of 15 months.

- In Sarawak that is situated closer to the equator than Sabah, temperature is already high when compared to other divisions hence, any small increase in temperature will affect the frond emergence stage, as reflected by -33 months (prior to harvest) > 28.12 °C and -34 months (prior to harvest) > 27.88 °C that had led to low yield, the lag time being 33 months.

CONCLUSION

The paper presented how long and short term time series analysis and data mining methods could be applied to understanding complex natural phenomena especially, to overcome the big data analysis issues in the climate domain. In this study, the approach consisting of ARIMA time series analysis, namely ARIMAX models and data mining techniques (J48 and JRip modules in WEKA) enhanced analysts' ability to extract more useful information on the complex time lagged effects of monthly climate anomalies (temperature and precipitation) on oil palm yield in the East and West Malaysia as well the country's ten administrative divisions.

The independent variables of best fit ARIMAX models for the East and West Malaysia oil palm yield data (long term) reiterate the significant stages within the 36 month-long oil palm production life cycle of previous research effects presented in the background and related work sections. Based on the results of this work, the climate change effects on West and East Malaysia's oil palm yield have similarities as well as dissimilates. Both East and West Malaysia that lie on either side of the China Sea have been affected by weather during flower opening and anthesis stages reflected in approximately 10 months later. But damage caused at frond emergence due to not so ideal temperatures and precipitation during this initial stage of the oil palm production cycle in West can be recuperated by good weather conditions during frond emission whereas, in the East it has not been indicated in the respective ARIMAX models i.e., the most vulnerable stage frond emergence for the East cannot be compensated for by subsequent good weather as per ARIMAX model. However, data mining results give a rule stating that the drought damage caused at the initial stage in the East could be compensated for with high temperature and high precipitation during the frond emission stage.

The combination of ARIMAX model and data mining techniques (JRip and J48) produced additional knowledge on the monthly temperature and precipitation anomalies that were related to high yield (long term data) in the West and East of Malaysia, and the critical production life cycle stages that were affected by bad weather with lagged effects. For instance, JRip rule gave further information on the temperature requirements (T_33) on ARIMAX model predictor PP_33 for high yield in West Malaysia. From the JRip rules, it was established that effects of bad weather during the initial stages of the oil palm production life cycle could be compensated for if the temperature during flower opening (and anthesis) and fruit maturation were good.

The ARIMAX and data mining results of short term yields with 36 monthly average temperatures prior to harvest as lag variables (representing the climate) showed the common and different stages of the oil palm production life cycle across the ten administrative divisions of Malaysia. The data mining results of this short term time series data at the administrative scale show the enormous difference in the time lag of the climate effects on yield. The lag period of Johor (4-13), Malacca (29-33), Pahang (9), Sabah (15) and Sarawak (33) show the variability in the time lag experienced in yield in these division during the five year period (2007-2011). The DM results again give further in-depth knowledge on the extent and the significance of the spatiotemporal variability in the recent climate change effects on oil palm yield across the divisions reintegrating the results of earlier studies by the authors (Shanmuganathan S., Narayanan, Mohammed, Ibrahim, & Khalid, 2014).

In summary, from the results of this analysis on the lagged effects of the climate change on Malaysia's oil palm yield (reflected in 10-24 months later) could be confirmed as stated in (Amanah investment bank berhad, 2014) and other studies presented in background and related work sections. This study, in addition to confirming the earlier research results also provide more clarify in terms of monthly temperature (^{o}C) and precipitation (mm) that had led to high and low yield across Malaysia at different spatiotemporal scales. Further research is underway for investigating the approach to yield forecasting at different more finer spatial scales.

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ENDNOTES

1 1 PB = 10^{15} bytes or 1000 terabytes.

2 Reductionism is about analysing and describing a complex phenomenon in terms of its simple or fundamental constituents.

3 Holistic approaches are based on the fact that parts of something are intimately interconnected and explicable only by reference to the whole as opposed to those of reductionist.

4 IPM practices are about not totally eradicating the pest populations but to keeping them at low levels so that they do not reach sufficient enough levels to cause any economic loss. It provides an alternative to complete reliance of a chemical alone approach applied in the past to controlling various pests of the oil palm industry specifically, to overcome the resistance of pests to treatment, build-up of residues in the environment, elevation of insects from secondary to primary pests and the disruption of populations of natural enemies (Darus & Wahid, 2001?). Later in 1995, Basri suggested techniques to establishing the relationship between the pest number and the damage or injury, and subsequently between damage and crop loss. Using the relationships as well as the crop yield prices of the economic produce, in this case oil palm, it could be possible to calculate the economic injury and an economic threshold level for each and every pest. Hence, the two main components of IPM are: sampling and economic threshold. More recently "Integrated Pest Management (IPM) is defined as the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and to keep pesticides and other interventions to levels that are economically justified and to reduce or minimize risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" (Food and Agriculture Organisation of the United Nations, 2014).

Section 11

Trade

Chapter 26
Climate Change, Trade Competitiveness, and Opportunity for Climate Friendly Goods in SAARC and Asia Pacific Regions

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ABSTRACT

This paper examines trade performance of climate friendly goods using some trade indices for South Asia and Asia Pacific countries during 2002 - 2008. Climate friendly goods (CFG) are those goods which are less harmful to environment. Paper identifies performance of Asia Pacific region in CFG trade with other nations. Most of the countries in Asia are importers of climate friendly goods and technologies. The Comparative advantage analyses indicate that Hong Kong, China, and Japan have comparative advantage in the production of CFG goods. Pakistan, Sri-Lanka, and India prefer to trade in CFG regionally and have shown interest in production and trade of clean coal technologies (CCT). East and South East Asia regions have comparative advantage in Solar Photovoltaic Systems (SPVS) and Energy Efficient Lighting (EEL). Japan, China, Malaysia and Macao show good in 2008 for SPVS.

INTRODUCTION

Recently, both year 2011 and 2012 produced a record number of extreme climate events including floods, heat waves, droughts, fires and snowstorms. Climate change is a threat to the modern human civilization, and also a challenge to the developmental activities in this century. *Climate Change* refers to a significant shift of climate lasting for an extended period of time. The Intergovernmental Panel on Climate Change (IPCC) reaffirms the climate change and the average global temperature increased by 0.74°C during 1906 – 2005, and it is expected to increase more in future (see IPCC Report 2007). In this context, even there is lot of limitations or obstacles for developmental activity; climate change provides certain opportunity to grow with newly climate

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friendly products. Climate friendly goods (CFG) are those goods which are less harmful to the environment, later we discuss on it in details. Now, question arises as follow: Is there any trade competitiveness in Climate friendly goods? How much competition are nations facing in climate friendly goods (CFG) in South Asia and Asia Pacific region? Has any country comparative advantage in any subcategory of climate goods? How much is the volume of trade opportunity for India, South Asia and Asia Pacific in CFG? Who are the potential trade partners within Asia Pacific and in the rest of the world? This paper attempts to answer these with quantifying trade opportunities of CFG in India, South Asia, and Asia Pacific.

This paper examines the trade performance of climate friendly goods (CFG) for South Asia and Asia Pacific nations and their trade partners using WITS data[1] for the period 2002 - 2008. Trade performance is judged using some trade indices and indicators. Trade indices like Export and Import shares, Revealed Comparative Advantage index (RCA), and Competitiveness index for trade of CFG and its sub categories are calculated to form a policy opinion on selected Asian countries' competitiveness, trade patterns, changing comparative advantage over time.

This chapter is organised as follows: Next section reviews relevant literature with define climate friendly goods, trade analysis and its importance. Section 2 describes data and analyses climate trade performance, Section 3 evaluates competitiveness, and also provides trade performance of sub categories of CFG. Section 4 analyse potential trade opportunity of CFG in South Asia and Asia Pacific region; and finally concluding remarks.

LITERATURE REVIEW

Climate friendly goods (CFG) are defined as components, products and technologies which tend to have relatively less adverse impact on the environment. The climate friendly goods (CFG) forms part of the broader group of environmental goods and services (EGS), which prevent, minimise or recover environmental damage, as well as problems related to waste, noise and ecological systems. It includes clean technologies, products that reduce environmental risk and minimise negative externalities and resource use. EGS can be classified as environmental goods comprising of pollution controlling equipments, environmentally preferable and resource management products. EGS has also environmental services that comprises of sewage services, reuse services, sanitation and similar services. CFG constitutes low carbon technologies such as solar photovoltaic systems, wind power generation, clean coal technologies and energy-efficient lighting. Some of the climate friendly goods/technologies are assisting in mitigation efforts by reducing GHG emissions and also improving adaptive capacity such as water conservation or improving access to energy.

Trade and Investment in CFGs and climate services have received attention as a triple win scenario where trade, climate and environment, and development all benefit (APTIR 2011). Countries prefer to concentrate on low energy consumption. Countries need to design sustainable and smart growth that entails sharply reduced GHG emissions which limits the global temperature. Various efforts (Rio meet in 1992, Kyoto protocol of 1997, Bali Action Plan of 2007, Copenhagen accord in 2009, Durban meeting in 2011, etc) have been made by international community to tackle the climate change.

The debate on trade, growth and environmental sustainability has arisen as trade and environment are not always positively related. Grossman and Krueger (1993) argue that trade affects environment through scale effects, technique effect and composition effect. With rapid increase of trade due to liberalization the ecological footprint including greenhouse gas emissions have risen sharply. This is the scale effect. The composition effect refers to the way trade liberalization changes countries' comparative advantages towards emission-friendly industries. Comparative advantage may change from 'carbon –intensive industries' to 'carbon leakage' due to 'pollution havens'. The technique effect refers to newly adopted technologies which reduce emission intensity as a result of trade. This may arise in two ways: (i) trade liberalization increases availability of climate friendly technology, (ii) trade increases income which may lead to prefer to clean environment (Grossman and Krueger 1995).

World Trade Organization (WTO) has recognized more than 150 (exactly it is 153) environmental goods and classified as (i) air pollution control, (ii) solid waste management and recycling systems, (iii) clean up soil and water, (iv) renewable energy plants, (v) heat and energy management, (vi) waste water management and potable water treatment, (vii) environmentally preferable products, (viii) natural resource and risk management, (ix) noise and vibration abatement, etc. World Bank has identified 43 out of 153 products list provided by the WTO. These are diverse products from wind turbines to solar panels to water saving equipments. All the lists floating around are consist of goods which tend to have benign impact on environment and lead to low carbon emanating processes.

One of the subcategories of CFG is clean coal technology that aims to improve energy efficiency and reduce environmental impacts, including technologies of coal extraction, coal preparation and coal utilization. Wind technology another sub category of CFG focuses on wind energy generation and is composed of three integral components: the gear box, coupling and wind turbine.

This study has selected 64 such goods under 6 digit HS code (2002) by putting together various lists that have been defined by various international organizations[2] recently. Following the World Bank (2008) this study divides these CFG into (i) Clean Coal Technologies (CCT), (ii) Wind Energy (WE), (iii) Solar Photovoltaic Systems (SPVS) and (iv) Energy Efficient Lighting (EEL). Besides these four sub groups the paper have also considered the fifth group as 'Other Codes' that consists of all HS codes (year 2002) not considered in the above four subcategories. This paper also performs the trade analysis for such subcategories.

CFG TRADE ANALYSIS AND ITS IMPORTANCE

The climate friendly goods are a subgroup and form a part of the broader group named environmental goods and services (EGS). An environmental good can be understood as equipment, material or technology used to address a particular environmental problem or as a product that is itself 'environmentally preferable' to other similar products because of its relatively benign impact on environment. Environmental services are provided by eco- systems or human activities to address environmental problems (see UN 2003 and also UNESCAP 2007). EGS can also be classified as Environmental Goods comprising of pollution management products, cleaner technologies and products, resource management products and environmentally preferable products. EGS also has environmental services comprising of sewage services, sanitation and similar other services.

The EGS were first discussed as part of the liberalizing agenda in the DOHA round of the multilateral trading round in 2001. The countries had wanted the tariff and non-tariff barriers to go down for trade of such EGS as this may lead to adoption of cleaner and cost effective technologies by firms and country at large and possibly mitigate climate change and improve energy efficiency. Liberalization has followed three routes namely the list approach, project/integrated approach and request for offer approach. Environmental Goods are always part of trade agenda but are subsumed within industrial or agricultural negotiations.

CFG (a subset of EGS) were discussed at the multilateral forums as countries wanted a smaller list to liberalize and where in negotiations could be easier done than concentrating on entire list of environmental goods. CFG constitutes low carbon growth technologies. For example WTO came out with a list of 153 goods for liberalization. Only 47 products were identified by the World Bank from 153 products list proposed by proponents of Environment Goods liberalization in the WTO. These 47 products comprised diverse products from wind turbines to solar panels to water saving shower but had dual usage problem as well for some products. Similarly OECD and ICTSD had their own lists of environmental goods and services. Free and liberal trade can make available such goods for countries that do not have access to these goods or where in domestic industry do not produce them in sufficient scale or at affordable prices. Additional market access can provide incentives to exporters to develop new products or technologies with less pollution that minimizes environmental impacts.

Global EGS industry was worth of 650 billion US dollars in 2008. Trade[3] in EGS was estimated at roughly a tenth of that amount (Jha 2008). Most of the exporters of EGS are the developed nation but few developing countries are also becoming important players in heat and energy management equipment, noise and vibration abatement and in environmental services like air pollution control and solid waste management (Jha 2008, 2009).

DATA AND ANALYSIS OF TRADE PERFORMANCE OF CFG

Following the World Bank, ICTSD, APEC, OECD and UNESCAP this study has identified 64 climate friendly goods (CFG) under 6 digit HS code (year 2002). Various international organizations recently define and identify CFGs. CFG trade data (in value, 1000 US dollar) is taken from the UN COMTRADE data (www.comtrade.un.org) for the year 2002 - 2008. This study considers CFGs as one category and estimates the above mentioned trade indicators for this category. The World Bank (2008) subgroups these goods further into clean coal technologies, Wind Energy, Solar Photovoltaic systems and Energy Efficient Lighting. The study besides these four sub groups have also considered 'Other Codes' as the fifth group which consists of all HS codes not considered in the four categories above. All these 64 CFG items are considered as single trade items for the estimation of the trade gravity model in our earlier studies[4] (Dinda 2011, 2013, 2014a,b). This paper is an extension of our earlier works and it adds value analyzing trade competitiveness within Asia Pacific.

Export Share of CFG Trade in Selected Nations in Asia Pacific Region

Export share is the ratio of country's total exports of the particular product to the World to country's total exports of all products to the World. The study has calculated the export share for countries and regional groups in Asia Pacific region during 2002 - 2008. Table 1 describes export share along with the gross CFG exports to the World originating from countries and ranks during 2002- 2008. For example India's export share of 1.95% in 2008 is calculated by taking ratio of gross CFG exports to World by India (354.98 million USD) to gross exports of all products to World by India (18185.92 million USD) and multiplied by hundred. China and Hong Kong have exports shares above the World average depicting good trade performance of such countries for CFG goods. ASEAN and SAARC region as a group's export share depict their relatively better performance. Similarly, for 2002 the study finds that Japan and Hong Kong performing better than the World average. Philippines and India are fifth and six positions in 2008 and have replaced Singapore and Malaysia from that position in 2002. South Korea and Thailand are ranked fourth and seventh in 2002 and 2008, respectively. India's export share figure was not

Table 1. Export Share of CFG in World Export for Countries and Regional Groups in 2002 and 2008

Countries	Export Share 2002(%)	Countries	Export Share 2008(%)
Japan	4.01	Japan	5.20
Hong Kong	2.56	China	3.41
China	2.27	Hong Kong	2.64
Korea, Rep.	2.06	Korea, Rep.	2.40
Singapore	1.65	Philippines	2.33
Malaysia	1.63	India	1.95
Thailand	1.59	Thailand	1.7
Regions			
Asia Pacific	2.38	Asia Pacific	2.38
APTA	2.162	APTA	2.162
ASEAN	1.63	ASEAN	1.58
SAARC	0.32	SAARC	1.73

significant in 2002, but India's CFG export performance has improved and captured the 6th position in Asia Pacific region in 2008. Over all, one finds that the share of CFG in world exports increasing for all countries and regions from 2002 to levels reached in 2008. It seems that Asian countries and/or Asian sub regions have realized the trade and importance of cleaner technologies and goods.

Import Share

Table 2 provides the import share of CFG in countries and regions in 2002 and 2008. The findings show countries with ranks 1 to 10 in both 2002 and 2008. The 10 countries above world import average share of 2.4% in 2008 are Kazakhstan, South Korea, Azerbaijan, China, Vietnam, Pakistan, Thailand, Russia, Australia and Hong Kong in Asia Pacific region. The 10 countries above world import share of CFG goods of 2.2% in 2002 are Papua New Guinea, China, Thailand, Turkey, South Korea, Malaysia, Singapore, Russia, Australia and Hong Kong in Asia Pacific region.

Table 2 indicates that most of the countries in Asia Pacific region are basically importers of CFG products from countries within regions. This paper confirms the above statement by looking at the regional group performance also. Import share of CFG increases in SAARC in 2008 while it declines in ASEAN.

EVALUATION OF COMPETITIVENESS

Competitiveness index is estimated as ratio of each country export of CFG to the world exports of CFG. Competitiveness in trade is broadly defined as the capacity of an industry to increase its share in international markets at the expenses of its rivals[5]. The competitiveness index is an indirect measure of international market power, evaluated through a country's share of world markets in CFG. The index takes a value between 0 and 100 percent, with higher values indicating greater market power

Table 2. Import share of CFG for Countries in Asia Pacific Regional Groups in 2002 and 2008

Countries	Import Share 2002 (%)	Country	Import Share 2008 (%)
PNG	4.05	Kazakhstan	4.10
China	3.60	Korea, Rep.	3.90
Thailand	3.254	Azerbaijan	3.86
Turkey	3.252	China	3.34
Korea, Rep.	2.97	Vietnam	3.29
Malaysia	2.95	Pakistan	2.80
Singapore	2.73	Thailand	2.77
Hong Kong	2.30	Hong Kong	2.50
Region			
APTA	3.32	Asia Pacific	2.62
Asia Pacific	2.66	APTA	3.18
ASEAN	2.93	ASEAN	2.34
SAARC	1.48	SAARC	1.8

of the country in question. Table 3 provides the results calculated competitive index for countries in Asia Pacific region in 2002 and 2008.

The figures in Table 3 show the most important economies in world export of CFG in 2008 and 2002. These are China, Hong Kong and Japan and Asia Pacific APTA, ASEAN and SAARC as regions. India, China and South Korea's competitiveness has improved in 2008 from 2002 position.

Revealed Comparative Advantages in CFG for Asia Pacific Countries

The study calculates two indices which indicate comparative advantage of countries in the CFG. Comparative advantage in some product means that country can produce the same product at lower relative cost and price in absence of trade. Since these prices are not observed, the researchers measure comparative advantage indirectly. There are several approaches to measure comparative advantage of countries.

Table 3. Competitiveness Index for Export of CFG by member states and Regional Groupings, 2002, 2008

Country	Competitiveness Index 2002 (%)	Country	Competitiveness Index 2008 (%)
Japan	12.479	China	12.621
China	5.523	Japan	10.506
Hong Kong	3.859	Korea, Rep.	2.622
Korea, Rep.	2.496	Hong Kong	2.526
Singapore	1.546	Singapore	1.356
Malaysia	1.145	India	0.917
Thailand	0.809	Malaysia	0.817
Russia	0.451	Thailand	0.772
Turkey	0.287	Turkey	0.462
Region			
Asia Pacific	28.992	Asia Pacific	33.6703
APTA	8.0427	APTA	16.1736
ASEAN	3.5004	ASEAN	3.3877
SAARC	0.024	SAARC	0.9446

The Michelaye index is defined as the difference of two shares. It is the share of one country's exports of the commodity of interest in its total exports and the share of the same country's imports of the same commodity in its total imports. The index takes a value between -1 and +1. A country is said to have a revealed comparative advantage if the value is greater than zero.

The Revealed Comparative Advantage is defined as the ratio of two shares. The numerator is the share of a country's total exports of the commodity of interest in its total exports, and the denominator is share of world exports of the same commodity in total world exports. The RCA takes a value between 0 and $+\infty$ (infinity). A Country is said to have a revealed comparative advantage if the value is more than one (or exceeds unity). Revealed Comparative index is given in Table 5.

The Michelaye index has been calculated for selected countries in Asia Pacific region (Table 4). It reveals that (except Japan and Hong Kong) Russia, India, China and Australia all have negative figures in almost all years from 2002 to 2008. This reinforces the point made above that most of the members in the region do not have comparative advantage in the production of CFG. However, they may be importing regionally from some good performers (Hong Kong, Japan, Philippines, Macao, and China). Table 4 shows that China and India improves over time.

Table 5 displays the RCA in production of CFG in Asian countries during 2002-2008. Table 5 shows that RCA figures for Japan, China and Hong Kong have figures greater than one and have a comparative advantage in the production of these CFG products in 2008. Japan and Hong Kong have figures greater than one in 2002.

Again we observe a rise of China. China had figure of 0.98 in 2002 while the figure in 2008 is 1.31. Any value of RCA greater than one indicates comparative advantage in the production of the good.

Table 4. Michelaye Index for CFG of selected countries in Asia Pacific region during 2002 – 2008

Year	Japan	HK	Russia	India	China	Australia
2002	0.022	0.002	-0.019		-0.013	-0.018
2003	0.024	0.001	-0.020	-0.006	-0.014	-0.017
2004	0.031	0.002	-0.021	-0.005	-0.016	-0.020
2005	0.030	0.002	-0.025	-0.005	-0.012	-0.020
2006	0.029	0.002	-0.025	-0.001	-0.009	-0.020
2007	0.032	0.003	-0.023	-0.002	-0.007	-0.020
2008	0.035	0.001	-0.023	0.003	0.001	-0.021

Trade Analysis of CFG Subcategories for Countries and Regional Groups

This section calculates Michelaye index, Revealed Comparative Advantage, Competitiveness Index for sub categories of CFG – viz., clean coal technologies, Wind Energy, Solar Photovoltaic systems, Energy Efficient Lighting, and 'Other Codes'.

Michelaye Index of CFG Subcategories for Regional Groups

Michelaye index identifies the sectors in which an economy or a group has a comparative advantage. A country is said to have a revealed comparative advantage if the value exceeds zero. The Michelaye index takes a value between -1 and +1. Michelaye index is measured for selected nations, and SAARC for CFG and its sub categories. Solar Photovoltaic Systems (SPVS) and Energy Efficient Lighting (EEL) are two sub categories of CFG in which the region as a whole has comparative advantage. All figures are negative for CFG broad category for Asia Pacific region. However, the above analysis and this one has shown that most of the member nations in the region do not have a comparative advantage in the production of CFG but they are net importers of CFG. Therefore, the study identifies only positive value of the Michelaye index for those countries and regional groups for sub categories of CFG. The results indicate that China, Hong Kong, India, Japan, Macao, Malaysia, Philippines, Thailand and Vietnam performs better for some sub categories in terms of export pattern to

Table 5. Revealed Comparative Analysis of CFG for Selected Members and Regional Groups in 2002 and 2008

Country	RCA in 2008	Country	RCA in 2002
Japan	2.0014	Japan	1.7408
China	1.3133	Hong Kong	1.111
Hong Kong	1.0156	China	0.986
Korea, Rep.	0.9251	Korea, Rep.	0.8931
Philippines	0.896	Singapore	0.7180
India	0.7507	Malaysia	0.7077
Thailand	0.6532	Thailand	0.6905
Malaysia	0.6118	New Zealand	0.4781
Singapore	0.5971	Turkey	0.4671
Macao	0.5297	Sri Lanka	0.2578
Turkey	0.5212	Russia	0.2459
Vietnam	0.3463	Australia	0.2206
New Zealand	0.342	Fiji	0.1630
Sri Lanka	0.2361	Macao	0.0980
Kyrgyz Republic	0.1883	Papua New Guinea	0.0669
Armenia	0.16916	Bangladesh	0.0328
Region			
ASEAN	0.6083	ASEAN	0.7081
SAARC	0.6648	SAARC	0.1376

Table 6. Michelaye Index for CFG subcategories for SAARC during 2002-2008

Year	CCT	WE	SPVS	EEL	Other	CFG
2002	-0.0008	-0.0002	-0.001	-0.00031	-0.0094	-0.012
2003	-0.0005	-0.0009	-0.0006	-9.6E-05	-0.0057	-0.007
2004	9.99E-05	-0.0008	-0.0003	-9.9E-05	-0.0062	-0.0068
2005	0.00014	-0.0008	-0.0003	-0.00011	-0.0064	-0.007
2006	-0.00014	-0.0006	-0.00016	-0.00012	-0.003	-0.0039
2007	-0.0004	-0.0009	-0.00024	1.01E-05	-0.004	-0.0052
2008	-0.0002	-0.0011	0.0011	3.44E-05	-0.0005	-0.0007

its own import pattern. For example China, India, Japan, Macao, Thailand and Vietnam have positive Michelaye index for Energy Efficient Lighting in some if not all during 2002 - 2008 while Japan, India, Macao and Malaysia perform better in Solar Photovoltaic systems.

Table 6 displays the Michelaye index for SAARC during 2002-2008. CFG sub categories Clean Coal Technologies, Solar Voltaic Systems and Energy Efficient Lighting show some positive values for some years (2008) indicating that SAARC as a region are net importers of CFG and sub category goods from the rest of the world. The positive values indicate the changing trade pattern of these countries in SAARC towards producing and exporting cleaner technologies.

Revealed Comparative Advantage (RCA) in CFG Categories for Pacific Nations in 2002 and 2008

Table 7 indicates that the Revealed Comparative advantage index for Energy Efficient Lighting is greater than one for China, Sri- Lanka and Macao in 2008 while it was greater than one for China and Thailand in 2002. This indicates that the share of EEL exports in the total exports of each of these countries is greater than the World share of EEL in Worlds total exports. The greater than one RCA figure for China in 2008 are also reflected in the alternative Michelaye index for China which is positive. This reconfirms that China is performing better than other is such technologies. The same happens with Macao in 2008 reconfirming that Macao has a revealed comparative advantage in 2008 and is reflected in its export pattern. Asia Pacific as a group has values of RCA greater than one in 2008 and 2002 indicative of its strong performance.

Table 7. RCA in EEL for countries and regions in 2008 and 2002

Country/ Regional Groups	RCA in Energy Efficient Lighting 2008	Country Regional Groups	RCA in Energy-Efficient Lighting 2002
China	6.019	China	5.529
Sri Lanka	1.922	Thailand	2.99
Macao	1.264	Sri Lanka	0.796
Thailand	0.979	Japan	0.593
Hong Kong	0.918	Korea, Rep.	0.558
India	0.4798	Hong Kong	0.311
Vietnam	0.219	Turkey	0.221
Korea, Rep.	0.142	Bangladesh	0.204
Japan	0.142	Macao	0.163
Turkey	0.126	Russia	0.119
Region			
Asia Pacific	1.906	Asia Pacific	1.525
ASEAN	0.283	ASEAN	0.892
SAARC	0.487	SAARC	0.480

Table 8 shows RCA in Solar Photovoltaic systems in 2008 and 2002 for member nations and regional groupings in Asia Pacific region. Japan, China, Malaysia and Macao show greater than one value in 2008 while Malaysia, Japan, Thailand, New Zealand and Hong Kong had greater than one figures in 2002. The Figures show the rise of China and Macao in 2008 to levels reached in 2002. All regional groups ASEAN and Asia Pacific regions show greater than one figure for SPVS in 2008. In the year 2002 only ASEAN and Asia Pacific had values greater than one.

Table 9 gives the figures for RCA for clean coal technologies. Pakistan and Singapore are the only countries in 2008 who have secured more than one figure in RCA. India is close at third with value of 0.85. It seems that SAARC countries have developed expertise in the production of CCT. It is also notable that no country in the Asia Pacific region had a comparative advantage in clean coal technologies in 2002. Also, no regional group has comparative advantage in the production of clean coal technologies. Maybe the world community at large need to rethink and review the policies related to clean coal technologies. Asia Pacific and ASEAN are already showing impressive export performance in relation to its import profile.

Table 8. RCA in Solar Photovoltaic Systems for Countries and Regions in 2008 and 2002

Countries/ Regions	RCA in Solar Photovoltaic Systems in 2008	Countries/ Regions	RCA in Solar Photovoltaic Systems in 2002
Japan	2.20	Malaysia	3.57
China	2.07	Japan	2.84
Malaysia	1.92	Thailand	2.00
Macao	1.28	New Zealand	1.29
Hong Kong	0.98	Hong Kong	1.19
Thailand	0.94	Singapore	0.80
Singapore	0.80	China	0.54
India	0.73	Korea, Rep.	0.43
Korea, Rep.	0.51	Australia	0.21
Vietnam	0.40	Turkey	0.20
Australia	0.29	Russia	0.16
Sri Lanka	0.27	Sri Lanka	0.06
Region			
Asia Pacific	1.28	Asia Pacific	1.41
ASEAN	1.03	ASEAN	1.99
SAARC	0.64	SAARC	0.03

Table 9. RCA in Clean Coal Technologies for Nations and Regionals in 2002 and 2008

Country/ Regional Groups	RCA In Clean Coal Technologies In 2008	Countries/ Regional Groups	RCA In Clean Coal Technologies In 2002
Pakistan	1.339	Japan	0.87
Singapore	1.117	Turkey	0.48
India	0.847	Singapore	0.20
Japan	0.829	Russia	0.18
New Zealand	0.491	Australia	0.11
Turkey	0.234	China	0.09
Russia	0.210	Malaysia	0.086
Australia	0.177	New Zealand	0.05
Thailand	0.157	Hong Kong	0.04
Hong Kong	0.067	Thailand	0.03
Malaysia	0.057	Korea, Rep.	0.027
Korea, Rep.	0.047	Sri Lanka	0.001
China	0.047	Papua New Guinea	0.0002
Region			
Asia Pacific	0.31	Asia Pacific	0.296
Asean	0.50	Asean	0.123
Saarc	0.86	Saarc	0.0005

Table 10 indicates that only Japan has a comparative advantage in the production of Wind technology both in 2002 and 2008.

Table 11 shows that Japan, Philippines, China, Hong Kong and South Korea have a comparative

Table 10. RCA in Wind Energy for Countries and Regions in 2002 And 2008

State/ Regions	RCA in Wind Energy in 2008	State/ Regions	RCA in Wind Energy in 2002
Japan	2.04	Japan	2.58
Turkey	0.57	China	0.59
China	0.47	Singapore	0.40
Korea, Rep.	0.46	Turkey	0.35
India	0.38	Korea, Rep.	0.25
Singapore	0.33	Russia	0.19
Thailand	0.22	Hong Kong	0.18
Australia	0.20	New Zealand	0.16
New Zealand	0.19	Thailand	0.14
Hong Kong	0.15	Australia	0.13
Region			
Asia Pacific	0.587	Asia Pacific	0.89
ASEAN	0.202	ASEAN	0.22
SAARC	0.329	SAARC	0.0006

Table 11. RCA in Other Codes in 2008 and 2002 for countries and Regions

Member Nation/ Regional Groups	RCA in Other Codes in 2008	Member Nation/ Regional Groups	RCA in Other Codes in 2002
Japan	1.99	Japan	1.58
Philippines	1.11	Hong Kong	1.16
China	1.08	Korea, Rep.	0.99
Hong Kong	1.07	China	0.96
Korea, Rep.	1.06	Singapore	0.71
India	0.75	Thailand	0.67
Thailand	0.65	New Zealand	0.52
Turkey	0.61	Malaysia	0.49
Singapore	0.59	Turkey	0.47
Malaysia	0.57	Sri Lanka	0.3
Region			
Asia Pacific	0.95	Asia Pacific	0.99
ASEAN	0.61	ASEAN	0.63
SAARC	0.66	SAARC	0.16

advantage in production of ‘Other codes’ in 2008 while Japan and Hong Kong got values greater than one in 2002. None of the groups have RCA advantage in 2008 and 2002.

It should be noted that the considerable improvement in RCA in other CFG items in China, South Korea and Philippines in 2008 from 2002.

Competitiveness Index for Trade in CFG Categories of India, SAARC, and Asia Pacific Region in 2002 and 2008

Competitiveness index shows the share of exports of one product by a country in World Exports of the same product. The higher value indicates an improvement in its competitiveness in relation to other countries. The values vary from zero to 100 indicating an ideal situation of full competitiveness. The ratio shows the countries international profile with respect to a product traded internationally.

Table 12 gives the index for member nations and Regional Groupings in Asia Pacific region for EEL. China, Hong Kong and Thailand are ranked one, two and three for 2008 while China, Japan and Thailand are ranked in the same serial in 2002. What is notable is the big gap between the figures of China and the second ranked nation in 2008 and in 2002. China got figure of 57.84% in 2008 while the second ranked nation got figure of 2.28%. In 2002 China got the figure of 30.96 while it was only 4.25 for second ranked Japan. Asia Pacific and APTA as regions perform better than other regional groups as far as competitiveness is concerned.

Table 13 shows the competitiveness index in SPVS for member states and regional groups. China, Japan, Malaysia are ranked one, two and three in 2008 while the ranking for 2002 is Japan, Malaysia and Hong Kong. Asia Pacific holds the top rank in 2008 and 2002.

Table 14 shows the competitiveness index in trade in CCT of nations and regions. Japan,

Table 12. Competitiveness Index for Trade in EEL of Nations and Regions in 2002 and 2008

Country/ Regional Groupings	Competitiveness Index 2008(%)	Country/ Regional Grouping	Competitiveness Index 2002(%)
China	57.84	China	30.97
Hong Kong	2.28	Japan	4.25
Thailand	1.16	Thailand	3.50
Japan	0.75	Korea, Rep.	1.56
India	0.59	Hong Kong	1.08
Korea, Rep.	0.40	Solomon Islands	0.85
Region			
Asia Pacific	63.85	Asia Pacific	42.78
ASEAN	1.58	ASEAN	4.41
SAARC	0.69	SAARC	0.08

Table 13. Competitiveness Index for Trade in SPVS of Nations and Regions in 2002 and 2008

Country/ Regional Groupings	Competitiveness Index 2008(%)	Country/ Regional Grouping	Competitiveness Index 2002(%)
China	19.85	Japan	20.33
Japan	11.55	Malaysia	5.78
Malaysia	2.57	Hong Kong	4.15
Hong Kong	2.44	China	3.06
Singapore	1.83	Thailand	2.34
Korea, Rep.	1.45	Singapore	1.72
Thailand	1.10	Korea, Rep.	1.19
India	0.89	New Zealand	0.32
Region			
Asia Pacific	42.85	Asia Pacific	39.53
ASEAN	5.73	ASEAN	9.83
SAARC	0.90	SAARC	0.006

Singapore and India are ranked one, two and three in 2008. The ranking was Japan, China and Singapore in 2002. Asia Pacific is at top rank in 2008 and 2002.

Table 15 provides the Competitiveness Index in Trade in the wind energy (WE) for countries and selected regional groups in 2002 and 2008. Japan, China and South Korea are ranked one, two and three, respectively; and corresponding the ranking are Japan, China and Singapore in 2002. Asia Pacific is at the top rank in 2008 and 2002.

Table 16 provides the Competitiveness Index in Trade in OC of countries and Regions in 2002 and 2008. Japan, China and Hong Kong are at top ranking in 2002 and 2008. Again Asia Pacific performs better than other groups.

POTENTIAL TRADE OPPORTUNITY

This chapter also investigates the potential trade opportunity of CFG for individual countries within the region and/or inter-regions especially with the European Union (EU), North America (the USA and Canada) and rest of the world. The gravity model[6] is used here to estimate the potential trade opportunity in Asia Pacific region (Dinda 2013, 2014a). In the context of climate change, these findings definitely help the policy makers to formulate certain policy to tap the *trade opportunity*. Following the standard gravity model, this paper investigates a new direction of potential trade opportunity in climate smart and/or environment friendly goods. This part of the study is based on (Dinda 2011, 2013, and 2014a,b) and provides certain insights regarding trade opportunity of CFG in SAARC and Asia Pacific region.

The following gravity model is considered here for the analysis

$$X_{ij} = \beta_0 + \beta_1 GDP_i + \beta_2 GDP_j + \beta_3 PCGDP_i + \beta_4\ PCGDP_j + \beta_5\ DT_{ij} + \beta_6\ D_{contig} + \beta_7\ D_{comlang} + \beta_8 D_{comlang\_ethno} + \beta_9 D_{colony} + \beta_{10} D_{comcol} + \beta_{11} D_{col45} + \beta_{12} D_{smctry} + \beta_{13} Trf_j + \varepsilon_{ij} \quad (1)$$

Table 14. Competitiveness Index for Trade in CCT of Nations and Regions in 2002 and 2008

Country/ Regional Groupings	Competitiveness Index 2008(%)	Country/ Regional Grouping	Competitiveness Index 2002(%)
Japan	4.35	Japan	6.22
Singapore	2.54	China	0.51
India	1.03	Singapore	0.44
Russia	0.66	Russia	0.32
China	0.45	Turkey	0.29
Region			
Asia Pacific	10.32	Asia Pacific	8.30
ASEAN	2.80	ASEAN	0.61
SAARC	1.22	SAARC	0.00008

where X_{ij} denotes the value of country *i* exports to country *j*, GDP_i and $PCGDP_i$ denote the exporting country's gross domestic product and per capita GDP, respectively; and GDP_j and $PCGDP_j$ denote the gross domestic product and per capita GDP of the partner of the exporting country, respectively; DT_{ij} denotes the distance between the exporting country and its partner (importing country); Trf_j is the (weighted average) tariff rate imposed by partner of exporting country, D_{contig}, $D_{comlang}$, $D_{comlang\_ethno}$, D_{colony}, D_{comcol}, D_{col45} and D_{smctry} are the dummy variables for contiguity, common language, colony, common colony, colony from 1945 and small country, respectively. In our regression analysis we have used the log values of all variables (except dummies).

Following Baldwin (1994), Deardorff (1995), Frankel et al (1997), Khatun (2010), Nilsson (2000) and Egger (2002), many Asian countries are far below the expected trade performance as the literature defines the term potential trade gap. This trade gap suggests that they could increase the export of CFG. These countries could increase their potential export trade of CFG nearly $7.35 billion USD. Among these countries, India ($4.2 billion USD) is on top, followed by Russia ($1.51 billion USD), Pakistan ($0.98 billion USD), Hong Kong China ($0.59 billion USD), Azerbaijan ($6.7 million USD), and Bhutan ($1.86 thousand USD), etc. These major countries have huge untapped potential trade of CFG. Intra and inter region groupings are done according to the partner country belonging to Asia, the EU, America, etc., it identifies individual trade partners of the reporting country.

Table 15. Competitiveness Index for Trade in WE of countries and Regions in 2002 and 2008

Country/ Regional Groupings	Competitiveness Index 2008(%)	Country/ Regional Grouping	Competitiveness Index 2002(%)
Japan	10.73	Japan	18.29
China	4.50	China	3.28
Korea, Rep.	1.31	Singapore	0.86
Singapore	0.74	Korea, Rep.	0.69
Turkey	0.50	Hong Kong	0.62
India	0.466	Russia	0.34
Hong Kong	0.38	Turkey	0.21
Region			
Asia Pacific	19.67	Asia Pacific	0.0004
ASEAN	1.13	ASEAN	1.69E-05
SAARC	0.47	SAARC	1.77E-09

Table 16. Competitiveness Index for Trade in OC of Countries and Regions in 2002 and 2008

Country/ Regional Groupings	Competitiveness Index 2008(%)	Country/ Regional Grouping	Competitiveness Index 2002(%)
Japan	10.45	Japan	11.31
China	10.36	China	5.39
Korea, Rep.	2.999	Hong Kong	4.017
Hong Kong	2.65	Korea, Rep.	2.77
Singapore	1.34	Singapore	1.54
India	0.92	Malaysia	0.799
Thailand	0.766	Thailand	0.784
Region			
Asia Pacific	31.97	Asia Pacific	27.80
ASEAN	3.38	ASEAN	3.12
SAARC	0.95	SAARC	0.03

Following Dinda (2014a), we analyse trade potential in two ways – intraregional and interregional. In Asia Pacific region, intraregional demand for CFG is very high. Actual intraregional imports were $61.2 billion USD in 2008, and the potential import gap was around $20 billion USD. Truly, Asian countries were net importers of CFG in 2008. This result also supports the World Bank (2008). Some countries were unable to fulfil its import demand during the crisis period in 2008, but these countries were capable of increasing their potential import trade of CFG nearly $19.84 billion USD only through intraregional trade. The major import potential countries are the Korean republic ($15.78 billion USD), Pakistan ($2.79 billion USD), Armenia ($7.37 million USD), and Bangladesh ($1.26 billion USD), etc.

Now we discuss the potential trade opportunity of CFG for selected countries in Asia Pacific region. Australia has potential to increase its trade potential particularly in climate friendly goods. Within Asia Pacific region, Australia has strong potential trade of CFG export to Nepal, Bangladesh, Georgia, Kyrgyz Republic, Bhutan, Azerbaijan, Turkey, Kazakhstan, Armenia, Japan, Russia, Iran and Pakistan. Australia can also increase CFG trade with Canada. The most important and encouraging Australia's CFG potential trade are with European Union, especially Luxembourg, Bulgaria, Slovenia, Romania, Czech Republic, Portugal, Greece, Slovak Republic, Poland, UK, Lithuania, France, Italy, Ireland, Finland and Austria. The estimated Australia's CFG exports potential are 21.7 million US dollar (USD) within Asia Pacific region and 29.99 million USD with EU. Australia has potential to increase export of CFG more than 52 million USD within Asia Pacific region and EU.

China has utilized moderately trade of CFG and still has potential to increase its trade of CFG. Within Asia Pacific region, China has strong trade potential to export to Korean Republic, Armenia, Hong Kong, Bhutan and Nepal. China can also increase CFG trade with small countries. The most important and encouraging China's potential trade of CFG are with European Union, especially Luxembourg and Austria. The estimated China's potential exports of CFG are 190 million US dollar within ESCAP region and 31.3 million USD with EU. China's potential export trade of CFG is higher in Asia Pacific than EU. China has strong trade potential particularly with South Korea and estimated potential export of CFG to Korean Republic is nearly 170 million USD. China should explore this potential trade and helps to stimulate to control climate change regional as well as global.

India has the potential to increase its trade opportunity of CFG. Within the Asia Pacific region, India can increase CFG export to Pakistan, Mongolia, Bangladesh, Armenia, Kazakhstan, Azerbaijan, Japan, Vanuatu, Russia, China, Kyrgyz Republic, New Zealand, Hong Kong, Korean Republic, Indonesia, Iran, Philippines, and Georgia, etc. India's most important and encouraging CFG trade partners in Europe are Luxembourg, UK, Latvia, Cyprus, Greece, Hungary, Slovenia, Slovakia, Austria, Finland, Ireland, Poland, Spain, Lithuania, Bulgaria, Romania, Denmark, Sweden, France, Italy and Czech Republic. India has trade potential to increase trade of CFG with Canada. India's estimated CFG exports potential is $4.976 billion US dollar within the Asian region and $1.01 billion USD with the EU. India's export potential trade of CFG is higher in the Asian region than the EU. India has strong trade opportunity of CFG with Pakistan, Bangladesh, China, Japan, Russia, and South Korea and the estimated potential export of CFG to these countries is nearly $4.9 billion USD. India's CFG export potential to Pakistan and Bangladesh alone is $4.4 billion USD. India can explore this potential trade and may revise the east look policy, and can also stimulate to control climate change in the region. India's CFG potential top trade partners in the EU are UK, France, Italy, Poland, Greece and Austria and the potential trade is nearly $1 billion USD. India has the potential to increase its export of CFG to Asia and EU approximately more than $6 billion USD.

Indonesia has potential to increase its trade of CFG. Within Asia Pacific region, Indonesia has strong trade potential of CFG export to Kazakhstan, Azerbaijan, Russia, Turkey, China, Iran, Samoa, Pakistan, Korean Republic, Afghanistan and Bangladesh. The most important and encouraging Indonesia's CFG potential trade are with European Union, especially Estonia, Austria, Finland, Romania, Latvia, Cyprus, Slovenia, Ireland, Spain, Denmark, Italy, Poland, Sweden, UK, Bulgaria and Czech Republic. The estimated Indonesia's CFG exports potential are 43.8 million US dollar within Asia Pacific region and 27.26 million USD with EU. Indonesia's export potential trade of CFG is higher in Asia Pacific region than EU. Indonesia has the strongest trade potential with China and estimated potential export of CFG is nearly 27.2 million USD. Indonesia's CFG potential trade top partners in EU are Italy, UK, Spain, Poland, Denmark, Sweden and Austria and potential trade is nearly 16.2 million USD. Indonesia has potential to increase its export of CFG to Asia Pacific and EU and total potential trade is approximately more than 71 million USD.

Japan has potential to increase its potential export trade of CFG. Within Asia Pacific region, Japan has strong trade potential in CFG export to Kyrgyz Republic, Bhutan, Armenia, Azerbaijan, Georgia, Papua New Guinea, Mongolia, Nepal, Afghanistan, Russia, Kazakhstan, Bangladesh and Sri Lanka. The most important and encouraging Japan's CFG potential trade are with European Union, especially Lithuania, Romania, Greece, Latvia and Finland. The estimated Japan's CFG exports potential are 175 million US dollar within Asia Pacific region and 23.9 million USD with EU. Japan's export potential trade of CFG is more in Asia Pacific region than EU. Japan has the strongest trade potential with Russia and estimated potential export of CFG is nearly 133 million USD. Japan's CFG potential trade top partners in EU are Greece and Romania and the estimated potential trade is nearly 15.6 million USD. Japan has potential to increase its export of CFG to Asia Pacific and EU and the estimated total potential trade of CFG is approximately 200 million USD.

Pakistan has a great potential to increase its trade potential particularly in CFG. Within Asia Pacific region, Pakistan has strong trade potential in CFG export to Russia, India, Viet Nam, Kazakhstan, Korean Republic, Nepal, Indonesia, Japan, Malaysia, China, Kyrgyz Republic, Hong Kong, Bangladesh, Australia, Singapore, Iran, New Zealand, Thailand, Azerbaijan and Turkey. Pakistan has a great trade potential in CFG trade with developing countries. The most important and encouraging Pakistan's CFG potential trade are with European Union, especially Ireland, Portugal, Hungary, Cyprus, Romania, Slovak Republic, Poland, Austria, Lithuania, Spain, Sweden, Italy, Czech Republic, France, UK, Denmark, Germany, Finland, Belgium, Greece and Netherland. Pakistan has trade potential to increase CFG trade of 17.5 million US dollar with the USA and Canada. The estimated Pakistan's CFG exports potential are 893.39 million US dollar within Asia Pacific region and 65.79 million USD with EU. Pakistan's export potential trade in CFG is more within Asia Pacific than any other region. Pakistan has the strongest trade partner in terms of export potential with India and estimated export of CFG to India is nearly 838.7 million USD. Pakistan should explore this potential trade and can stimulate to control climate change in the region. Pakistan's CFG potential trade top partners in EU are UK, Germany, France and Italy, and potential trade is nearly 55.49 million USD. Pakistan has potential to increase its export of CFG to ESCAP and EU members, and the US and Canada approximately more than 976 million USD.

Philippines have potential to raise its export trade of CFG particularly. Within Asia Pacific region, Philippines have strong potential trade of CFG export to Bangladesh, Pakistan, Russia, New Zealand and Turkey. The most important and encouraging Philippines' CFG potential trade with European Union, such as Czech Republic, Slovenia, Portugal, Bulgaria, Sweden, Latvia, Italy, Greece, Finland and Spain. The estimated Philippines' CFG exports potential are 2.38 million US dollar within Asia Pacific region and 2.25 million USD with EU. Philippines have the strongest potential trade with Russia in Asia and Italy in EU.

South Korea has potential to increase its trade potential particularly in CFG. Within Asia Pacific region, South Korea has strong trade potential in CFG export to Afghanistan, Azerbaijan, Nepal, Vanuatu, Japan and Kyrgyz Republic. The most important point is that it does not encourage Korea's CFG potential trade with European Union, except Luxembourg. The estimated South Korea's potential export of CFG is 1.043 billion US dollar within Asia Pacific region. Republic of Korea has the strongest trade potential with Japan and estimated potential export of CFG with Japan is nearly 1.042 billion USD. Republic of Korea should explore and gain from this potential trade gap.

Sri Lanka can increase its potential trade of climate friendly goods. Within Asia Pacific region, Sri Lanka has strong potential export of CFG to Philippines, Indonesia, Iran, Malaysia, Mongolia, Thailand, Pakistan, Singapore and Kazakhstan. Sri Lanka can also increase the CFG trade with Canada. The most important and encouraging Sri Lanka's CFG potential trade are with European Union, especially Cyprus, Austria, Denmark, Latvia, Hungary, Romania and Spain. The estimated Sri Lanka's potential exports of CFG are 425 thousand US dollar within Asia Pacific region and 177 thousand US dollar with EU. Sri Lanka has potential to increase export of CFG within Asia Pacific and EU.

Thailand has moderate potential to increase its trade of CFG. Within Asia Pacific region, Thailand has strong potential export of CFG to Kazakhstan, Armenia, Iran, Mongolia, Nepal, Georgia, Bhutan and Russia. The most important and encouraging Thailand' CFG potential trade are with Luxembourg and Lithuania in EU. The estimated Thailand's CFG exports potential are 1.5 million US dollar within Asia Pacific region and 116 thousand USD with EU. Thailand can increase its potential trade of CFG around 1.6 million US dollar.

There is a huge variation in the potential trade gap among nations. One of the major reasons is the variation of tariff rates between countries. Other reasons may be lack of awareness and knowledge, insufficient technology, lack of skilled labour for production of CFG, lack of trade facilitations etc.

CONCLUSION

This paper examines the trade performance of climate friendly goods. This study evaluate trade through assessing some trade indices such as Export and Import Shares, RCA, Competitiveness for India as well as Asian countries and some regional groups for trade of CFG and its sub categories for years 2002 - 2008. Analysis of the Export and Import shares of CFG indicate that all are importers of such goods from Asia region and some of them are importing from other parts of the world.

The Comparative advantage indicates that Hong Kong, Japan and China (in 2008 only) have comparative advantage in the production of CFG goods and are also net exporters of CFG. Major countries in the region do not have comparative advantage in the production of CFG. The competitiveness index shows that China, Hong Kong and Japan and Asia Pacific region are significant contributors of CFG export in the World. Competitiveness of India, China and South Korea has improved during 2002 - 2008.

Some SAARC members such as Pakistan and Sri-Lanka and India (2002) prefer to do trade in CFG regionally. SAARC have shown interest is production and trade of clean coal technologies. RCA results show that Pakistan and Singapore have only comparative advantage in clean coal technologies (CCT) in 2008, and India is close to them. It suggests that SAARC countries have developed expertise in the production of CCT. Now, the policy makers should rethink and review the policies related to clean coal technologies.

As per Michelaye index for sub categories of CFG, SPVS and EEL have comparative advantage in Asia region. Thailand, Vietnam and Macao perform better in terms of their export pattern during 2002-2008. ASEAN does better in terms of export pattern to its own import structure for the sub category SPVS only. China is performing better than other in EEL. Japan, China, Malaysia and Macao show greater than one RCA values in 2008 for SPVS. Japan has a comparative advantage in the production of Wind technology. Japan, Philippines, China, Hong Kong and South Korea have a comparative advantage in production of ‘other’ items in 2008. ASEAN as a group has regional bias towards its own region for all codes except SPVS in 2002 and 2008. SAARC as a group has regional bias for EEL in 2002 and 2008 but CCT in 2008. The above analyses provide the actual position of each country with respect to trade of CFG and its sub categories.

Gravity analysis helps us to understand the above observed trends. Applying gravity model this chapter measures potential trade gap in CFG for individual country and identifies corresponding their potential trade partners. This study has some limitations in terms of detail disaggregated updated information. More depth study is required using goods specific tariffs, size of the economy, endowments, policy, transparency, regulations or infrastructure matter, etc. This is the direction of future research.

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KEY TERMS AND DEFINITIONS

Climate Change: Climate change refers to any significant change in the measurement of climate lasting for an extended period of time. Over the past century, human activities have released large amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. Major greenhouse gases are generated from burning fossil fuels. Deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere. As a result, average global temperatures increased by 0.74ºC during 1906 – 2005, and a further increase of 0.2ºC to 0.4ºC in the next 20 years is expected (IPCC). Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather. Many places have seen variations in rainfall - resulting in more droughts or intense rain and more floods, as well as more frequent and severe heat waves (IPCC Reports). Climate change refers to a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties, which persist for an extended period, typically decades or longer. Any change in climate may be due to natural variability or as a result of human activity. Anthropogenic warming is influencing many physical and biological systems.

Climate Friendly Goods: Climate Friendly Goods are defined broadly as products, components, and technologies which tend to have a relatively less adverse impact on the environment. CFG constitute low carbon growth technologies. For example, one subcategory of CFG is clean coal technology, which improves energy efficiency and reduces environmental impacts. Clean coal technology includes technologies of coal extraction, coal preparation, and coal utilization. Wind technology (another sub category of CFG) focuses on wind energy generation and is composed of three integral components: gear box, coupling, and wind turbine. The study also observes that trade of such CFG has a regional bias for most of the countries in the region, although, almost all are net importers from Japan, Hong Kong, and more recently China. CFG is a part of a wider group of named environmental goods and services (EGS). Environmental goods can be understood as equipment, material or technology used to address a particular environmental problem or as a product that is itself *environmentally preferable* to other similar products because of its relatively benign impact on environment. Environmental services are provided by ecosystems or human activities to address environmental problems and to help minimize environmental damages and protect the bio-sphere of the earth. EGS can be classified as environmental goods comprising of pollution management products, cleaner technologies and products, resource management products and environmentally preferable products. EGS also has environmental services comprising of sewage services, reuse services, sanitation, and similar services, and others.

Competitiveness Index: Competitiveness index is estimated as ratio of each country export of CFG to the world exports of CFG. Competitiveness in trade is broadly defined as the capacity of an industry to increase its share in international markets at the expenses of its rivals. The competitiveness index is an indirect measure of international market power, evaluated through a country's share of world markets in CFG. The index takes a value between 0 and 100 percent, with higher values indicating greater market power of the country in question.

Gravity Model: The traditional gravity model is drawn on an analogy with Newton's law of gravitation, which states that the gravity between two objects is directly related to their masses and inversely related to the distance between them. A mass of goods or factors of production supplied at origin *i*, Y_i, is attracted to a mass of demand for goods or factors of production at destination *j*, Y_j, but the potential flow is reduced by the distance between them, D_{ij}. Strictly applying the analogy, $X_{ij} = \frac{Y_i Y_j}{D_{ij}^2}$. It gives the predicted movement of goods or factors of production between *i* and *j*, X_{ij}. The gravity model is initially presented as an intuitive way of understanding trade flows. The trade gravity model is based on the idea that trade volumes between two countries depend on the size of the two countries and the distance between them. Distance can be physical, cultural or/and political.

Michelaye Index: The Michelaye index is defined as the difference of two shares. It is the share of one country's exports of the commodity of interest in its total exports and the share of the same country's imports of the same commodity in its total imports. The index takes a value between -1 and +1. A country is said to have a revealed comparative advantage if the value is greater than zero.

Revealed Comparative Advantage: The Revealed Comparative Advantage is defined as the ratio of two shares. The numerator is the share of a country's total exports of the commodity of interest in its total exports, and the denominator is share of world exports of the same commodity in total world exports. The RCA takes a value between 0 and $+\infty$ (infinity). A Country is said to have a revealed comparative advantage if the value is more than one.

Trade Opportunity: Trade opportunity is the scope of nation to increase its trade. Basically it is a trade gap of a country with its trade partners. Researchers can estimate trade value and measure how well a bilateral trade flow performs relative to the mean as predicted by the gravity model. So, the *potential trade gap* means how far below the actual trade value is from the predicted trade value. This *potential trade gap* suggests that there is a scope to increase the export of climate friendly goods (CFG) with trading partners. The total estimated *export potential trade gap* in CFG in Asia was around \$30 billion US dollar in 2008.

Trade: Trade plays a major role in innovations and disseminating technologies. It is presumed that liberalized trade is a potent driver for technological innovation. It is expected that advanced know-how and environment friendly technologies will be readily available through liberalised trade.

ENDNOTES

1 Trade statistics uses World Integrated Trade Solution (WITS) data base where in UN commodity trade data is used for estimating the various indices. For comparison purpose the study reflects figures for 2002 and 2008 mainly and for some regional groups like SAARC and ASEAN. All countries of ASEAN, APTA and SAARC fall under Asia Pacific region, and we have taken Asia Pacific as one region for our analysis. This study focuses on the crisis period and pre-crisis period since 2002.

2 The list is arrived by defining concordance series from series of list given by the World Bank, ICTSD, WTO, APEC and the OECD.

3 CFG exports to the world were worth 38 billion dollars out of total World Exports of 1488 billion USD in 2008 with World export share of CFG working out to be 2.5% in the year 2008. This share has varied between 2.3% in 2002 to 2.8% in 2009. World imports

of CFG were worth 38 billion USD out of total World Imports of 1557 billion US % in 2008 with World Import share of CFG working out to be 2.4% and this share has varied from 2.2% in 2002 to 2.68% in 2009.

4 It should be noted that this study was initiated at UNESCAP Bangkok. This paper is based on data set that also used in UNESCAP report (APTIR 2011) and other papers also. Our part of trade performance analysis results is very similar to the work of UNESCAP's report (2011).

5 See UNASIA PACIFIC Handbook, Trade Statistics in Policy Making, 2007

6 For detailed, see, Anderson (1979), Anderson and Wincoop (2004), Baldwin and Taglioni (2006), Tinbergen (1962), Deardorff (1995), Frankel et al. (1997), and Dinda (2014a)

Chapter 27

Greenhouse Gas Mitigation through Energy Efficiency:
Perform, Achieve, and Trade (PAT) – India's Emission Trading Scheme

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ABSTRACT

Pursuant to the Thirteenth Conference of Parties to the UNFCCC held at Bali in 2007, based on Nationally Appropriate Mitigation Action plan, India has introduced its very own Emission Trading Scheme (ETS) called Perform, Achieve and Trade (PAT) market mechanism. The country has already achieved remarkable success in the renewable energy front. This chapter studied the existing policy regime of renewable energy and energy efficiency, and tried to understand how far the country practically can achieve the objective enshrined by PAT mechanism. This paper highlighted the background of the market based ETS, where various policies and legislation were put in place to provide energy efficient service and energy efficient system to the large energy intensive sectors of Indian economy. However it is not conducive to come to a conclusion regarding PAT's success or failure unless the First PAT cycle is completed, i.e. 2012-13 to 2014-15 compliance period is over.

INTRODUCTION

A technological society has two choices. First, it can wait until catastrophic failures expose systemic deficiencies, distortion and self-deceptions… Second; a culture can provide social checks and balances to correct for systemic distortion prior to catastrophic failures. - Mahatma Gandhi

In 1980s, with increasing scientific evidence of human interference in the global climate system raised public concern. Climate change has mounted as a political agenda around the globe. As an effort by the United Nation to provide the governments and policymakers with a clear scientific view of what is happening to world climate, in 1989 the Intergovernmental Penal on Climate

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Change (IPCC) was set up by the World Metrological Organization and the United Nation Environment Programme. The IPCC in its first report in 1990, concluded that the growing accumulation of greenhouse gases (GHGs) in the atmosphere would *'enhance the greenhouse effect, resulting in an additional warming of the earth's surface'* by the next century, unless measures were taken to limit emissions. Responding to this report the United Nation General Assembly in December 1990, launched negotiations to formulate an International treaty on global climate protection, which later became United Nation Framework Convention on Climate Change (UNFCCC). The negotiation started on February 1991, lasted for 15 months and the convention was adopted on May 1992 (UNFCCC, 1992).

India signed the UNFCCC on 10th June 1992 and ratified it on 01st Nov 1993 and it has been enforced in March 1994, after being ratified by 50 other countries. On 11th December 1997, at the third Conference of Parties (COP) to UNFCCC, held at Kyoto, Japan, adopted a Protocol, which came in to force on 16th February 2005. The Protocol set binding targets for 37 industrialized countries and the European community for reducing GHG emissions by of 5% against 1990 levels over the five-year period of 2008-2012. Although there were no such target set for any of the developing country, but to engage developing countries in mitigation action, in 2007 during the thirteenth COP, which held at Bali, Indonesia, for the first time the concept of Nationally Appropriate Mitigation Action (NAMA) has been adopted (Sharma & Desgain, 2013, p. 8).

Following the resolution adopted at Bali, to fulfil its commitment towards environment at the international level India launched eight priorities as national action plan to counter climate change based on NAMA principle. The National Mission for Enhanced Energy Efficiency (NMEEE) is one of the eight priority action plan to increase efficiency in the energy sector with an objective to reduce overall GHGs emission in the country.

This chapter comprises of five sections. After the introductory discussion, Section-1 provides a brief insight by describing the key question of the study and provides an outline of the following sections. The Section-2 describes the overall economic scenario of the country and contribution of various sectors in the GDP of the nation, their respective level of energy consumption and emissions. Depending on the intensity or quantity of energy consumed and the amount of investment required for switching over to energy efficient equipments *The Energy Conservation Act, 2001* (hereinafter The EC Act.), identified 15 large energy intensive sectors of the economy. However, out of 15 energy intensive sectors only 8 were included in the 1st PAT cycle i.e. 2012-13 to 2014-15. These sectors have significant scope and potential for improvement in their energy consumption.

The Section-3 highlights the taxonomy of the policies, enactments and institutional establishment. India is one of the top emitting nations of the world and to fulfil its commitment under the UNFCCC to take NAMA Plan for sustainable development and also considering the level of energy consumption and sectorial emission, adopted various policies and measures regarding promotion of Renewable Energy and Renewable Purchase Obligations, Energy Efficiency, Energy Self-sufficiency measures with an objective to make India an energy secure nation.

The Section-4 contextualises the concept and evolution of Emission Trading/Tradable Allowances as an economic instrument to mitigate climate change. This chapter shall also focus on India's very own ETS, i.e. Perform Achieve and Trade (PAT) market mechanism, how the mechanism had been adopted and the amendments made to The EC Act, 2001 for its smooth functioning.

Finally the Section-5 contains the concluding remarks, which will revisit the research question and analysis conducted in the preceding sections.

BACKGROUND

Study/research suggests that, till date there are no specific titles available on policy framework of India's emission trading market mechanism as it is a very recent introduction. One of the studies of Kumar and Agarwala (2013a) mainly concentrated on the issues of boundary and target setting PAT Energy Saving Certificates (ESCert). The study also discussed briefly PAT policy mechanism on energy efficiency and institutional network for ESCerts trading. Whereas, another study of Kumar and Agarwala (2013b) explored the techno-economic feasibility evaluation of innovative energy model of PAT ESCerts by taking in to account the geographical advantages, government policies, regional incentivise etc. While the present chapter has mostly emphasised on the policy aspect and evolution of India's emission trading market mechanism. However, it has explained the economics of Perform, Achieve and Trade market mechanism in a very limited way. At present there are two energy certification schemes coexists together in the country, (i) the Renewable Energy Certificate mechanism introduced in 2010 (Central Electricity Regulatory Commission Regulation, 2010a and 2010b); (ii) ESCerts under the PAT mechanism introduced in 2012.

The main question in this context is: *How far the implementation of Perform, Achieve and Trade market mechanism will benefit India in realizing/attaining its goal to enhance energy efficiency in the energy intensive sectors vis-a-vis Greenhouse Gas mitigation?* The main issue in this study is that with the existing policy regime of renewable energy and energy efficiency, how far the country practically can achieve the objective enshrined by PAT market mechanism. One of the key issues for the study is to identifying the important sectors of the economy those contributes most to the GDP and also responsible for most of the emissions in the country. Secondly, the policies and measures adopted by India to balance the energy gap, i.e. energy supply & demand and to reduce GHGs emission. Finally, understanding the regulation of Emission Trading Mechanism in India. Despite the fact that the PAT mechanism is introduced recently, under the existing renewable energy policy regime, which shows much achievements, to what extant contribute in achieving the goal of PAT. This study highlighted the background of the market based ETS, where various policies and legislation were put in place to provide energy efficient service and energy efficient system to the large energy intensive sectors of Indian economy.

The methodology adopted is mostly employs legal and policy analysis of the Indian Renewable Energy sector, Energy Efficiency policies. Primary sources are reviewed to identify the areas of analysis and secondary sources are consulted to substantiate the author's own opinion. The study based on various sources, most of the sources are Government of India reports, working papers and national legislations and with few International Treaties. In terms of data, those are used in this study, sources belong to International and National organization and the remaining sources are books, journals and articles.

SECTORIAL CONTRIBUTION TO ECONOMIC DEVELOPMENT

India's development agenda focuses around the need for rapid economic growth as an essential prerequisite to poverty elevation and improved standard of living. The economic reforms of 1991 resulted in speedy growth of the Indian economy. Although the average GDP growth rate has been around 8% during 2004-2008, 27.5% of the population were still living below the poverty line in 2004-05 and 44% population of the country is still has no or very limited access to electricity.

In the words of former Prime Minister of India, Late Mrs. Indira Gandhi *"poverty is the worst polluter"*. The Approach paper to the Eleventh Five Year Plan (FYP), i.e. 2007-08 to 2011-12, emphasized that rapid economic growth is an essential prerequisite to reduce poverty. Therefore development and poverty eradication will be the best way of adaption to climate change (Prime Minister's Council, 2008, p. 13).

As per the National GHG Inventory, Carbon Dioxide (CO_2) emissions from the industry sector in 1994 are estimated by taking into account emissions from paper, sugar, cement, iron and steel, textile, bricks, fertilizer, chemical, aluminium, ferroalloys, non-ferrous, food and beverages, leather and tannery, jute, plastic, mining and quarrying, rubber, and all other industries, which together accounted for almost 31% of the country's emissions (Ministry of Environment & Forest [MoEF], 2004). Coal and petroleum oil products are used in these industries as primary energy sources in substantial quantities. The CO_2 emission from the industrial sector can broadly be classified into two heads, i.e. *(i) process related emission; and (ii) emission due to fuel combustion in the industries.* Out of total estimated 250 million tonnes (MT) of direct CO_2 emissions from the industry in 1994, approximately 60% were due to energy use by the industries (Prime Minister's Council, 2008, p. 22).

In May 2010 India released the Report on Greenhouse Gas Inventory 2007. This was the long anticipated first comprehensive inventory of India's GHG emission since it has prepared its first GHGs inventory for the base year 1994 (Reddy, 2010). "This assessment provides information on India's emissions of Greenhouse gases (Carbon Dioxide [CO_2], Methane [CH_4] and Nitrous Oxide [N_2O]) emitted from anthropogenic activities at national level from five sectors as such, Energy, Industry, Agriculture, Waste and Land use, land use change and Forestry (LULUCF)" (MoEF, 2010).

Due to effective policies and their proper implementations the GHG emissions intensity of India's GDP declined by more than 30% during the period 1994-2007. In the year 2007, United States of America (USA) and China's emissions were almost four times higher than that of India (Reddy, 2010).

The Table 1 shows the top 10 GHGs emitting nations of the world and GHGs emission by India in 2010, which account for 5.6% of the total global emissions in that year. India's GHGs emission is significantly lower than the emissions of China and USA, who are responsible for 22% and 13% of the global emissions. Under the Copenhagen Accord to adopt Nationally Appropriate Mitigation Action Plan, India pledged that it will endeavour to reduce the emissions intensity of its GDP by 20-25% by 2020 in comparison to the 2005 level and further clarified that all the efforts will be voluntary in nature and will not have a legally binding character and the emissions from the agriculture sector will not form part of the emission intensity (India's Domestic Mitigation Actions, 2010).

Table 1. Country wise GHGs emission and global share

Sl. No.	Country	Current Emissions ($MtCO_2e$ 2010)	Share of Global Emissions (%)
1.	China	11182	22
2.	USA	6715	13
3.	EU-27	4999	10
4.	India	2692	5.4
5.	Russian Federation	2510	5.0
6.	Indonesia	1946	3.9
7.	Brazil	1621	3.2
8.	Japan	1379	2.8
9.	Canada	728	1.5
10.	Mexico	661	1.3

Source: (United Nation Environment Programme, 2012)

Major Emitters of Indian Economy

India's economy is one of the fastest growing economies in the world. India's economy has experienced an average 7% growth rate in the last decade. With 2.4%, India stands at 11th position in the world in energy production and holds the 6th position in energy consumption with 3.5% (South Asia Monitor, 2006). So the wide gap between the level of energy production and consumption can be understood very clearly.

The following lines of Prime Minister's forwarding letter in the Eleventh FYP are well enough to state the India's thrust for Energy Efficiency (Planning Commission [PC], 2008a).

Availability of affordable energy is critical for our growth. With international oil prices rising sharply over the last couple of years, and coal prices more recently, our efforts towards energy security have acquired urgency. The Eleventh Plan will work towards policies for various energy sectors that are consistent with the optimal use of the different sources of energy. The Plan emphasizes the need for energy conservation, increasing energy efficiency, and development of renewable sources of energy.

Coal, which is one of the dirtiest hydrocarbon fuels, account for nearly 70% of the country's energy needs. The remaining energy need is fulfilled mostly by oil, which is imported and the increasing oil price is also a burden for the growing economy. With 7% of the world's coal India possesses 4th largest coal reserve in the world. As India is party to all the major environmental conventions and treaties and due to its commitment towards environment and sustainable development coupled with reasons for energy security, India is opting policies for energy efficiencies and the ETS is part of those commitments.

Depending on the intensity or quantity of energy consumed and the amount of investment required for switching over to energy efficient equipments *The EC Act, 2001* (The Energy Conservation Act, 2001), identified 15 large energy intensive sectors of the economy. But, out of 15 energy intensive sectors only 8 were included in the 1st PAT cycle i.e. 2012-13 to 2014-15 and these sectors have significant scope for improvement in their energy consumption. The 8 sectors are briefly discussed as follows:

Aluminium

Aluminium is the second most abundant metallic element in the earth's crust after silicon and second most used metal after steel. The most commercially mined aluminium ore is bauxite and India has the fifth largest reserve of bauxite, with deposit of about 2.3 billion tonne which is 6.7% of the world reserve (Ministry of Power [MoP], 2012, p. 6).

In the year 1989 the industry was decontrolled and followed by de-licensing in 9191, which resulted in growth of 12% compare to 6% in 1980s. At present the per capita consumption of aluminium in India is 1.5 kg with an annual demand of 1.8 MT. But following the growth of the economy it's projected that the primary aluminium demand is likely to grow up to 6 MT by 2025 (Indian Mirror, n.d.).

The aluminium production process involves both upstream and downstream activities. The upstream activities involve mining and refining while the downstream activities involve smelting, casting and fabricating. The process of smelting is very energy intensive and consumes around 85%-90% of electrical energy (MoP, 2012, p. 6).

Cement

The cement industry is a century old industry in India. The first cement industry was setup at Porbundar, Gujrat in 1914. The liberalization policy of the cement industry has brought noticeable growth to the industry. The price and distribution control was completely removed by the government in 1989 and subsequently in 1991 the industry was de-licensed (Department Related Parliamentary Standing Committee on Commerce, 2011). At present India stands second after China in cement production in the world. The industry directly employs 70,000 people and also opens huge avenues for indirect downstream employment. It accounts for 5% of the excise collection of the country (PC, 2008b, p. 170). Cement is vital to the construction sector and all infrastructural projects. The construction sector alone constitutes 7% of the country's GDP (India Brand Equity Foundation, n.d.).

Coal and electricity are the main source of energy used by the industry. In some of the industries energy accounts for 40% of the total manufacturing cost and coal accounts for 15%-20% of the total production cost (MoP, 2012, p. 8). The average energy consumption however is around 725 Kilocalorie per kilogram (Kcal/kg) of clinker (thermal energy) and 80 Kilowatt hour per tonne (kWh/T) of cement (electrical energy). The best thermal and electrical energy consumption recently achieved by the Indian industry is as low as 667 Kcal/kg of clinker and 67 kWh/T of cement, which are comparable to the global best of 660 Kcal/kg and 65 kWh/T respectively (Indian Bureau of Mines, 2012, p. 6). As the availability and quality of grid power supply is a problem the use of captive power has been increased in the industry. By the end of the Tenth FYP i.e. 2002-03 to 2006-07 the captive power generation capacity was estimated around 1825 Megawatt (MW), of which 61% is diesel based and remaining 39% coal based (PC, 2008b, p. 171).

It has been estimated that nearly 5% energy saving is possible in both thermal and electrical energy consumption in cement plants through the adoption of various energy conservation measures.

The Working Group on Cement for Twelfth FYP period has projected that the industry is expected to grow at the rate of 10.75% corresponding to GDP growth of 9% (Indian Bureau of Mines, 2012, p. 10). To reduce environmental impact of the industry the Twelfth FYP has recommended incentivising non-polluting cement plants adopting newer technologies and granting cogeneration of power through waste heat recovery status of renewable energy (PC, 2013, p. 117).

Chlor-Alkali

The chlor-alkali industry forms a significant part of the Indian chemical industry and produces 74% of the total basic chemical produced in the country. The major products of chlor-alkali industry are Caustic Soda (NaOH), Chlorine (Cl_2) and Soda Ash (Na_2CO_3), which are used as follows:

1. **Caustic Soda:** Is used in soaps and detergent industry, pulp and paper industry, textile processing industry, aluminium smelting, plastic polymers and rayon grade pulp.
2. **Chlorine:** A co-product of caustic soda industry is very important for manufacturing of Polyvinyl chloride, one of the five major thermoplastic commodity plastics. Besides this, it is used in disinfection of drinking water, pharmaceutical industry and various other chemical industries.
3. **Soda Ash:** Is used in glass industry, soaps & detergents, silicates and various other chemical industries.

The Chlor alkali process is the main process for manufacturing of caustic soda and chlorine production all over the world. The process involves the application of direct electric current to a brine (water and salt) solution that results in producing caustic soda and chlorine simultaneously, while soda ash is produced during a different process (Sinha & Das, 2012). Chlor-alkali industry is an energy intensive industry and energy costs around 50% to 60% of the total cost of production. In the electrolyses process of Sodium Chloride Solution 85% to 90% electric power is used.

Fertilizer

India is an agriculture based country and nearly 60% of the people depend on agriculture sector. Agriculture in itself contributes more than 18.5% of the GDP of the country (Dave, n.d.). Because of the strong agricultural base there has been a significant growth in fertilizer industry in the recent past. India holds second position in production of fertilizers in the world, with consumption of 28.12 MT of Nitrogen–Phosphorus–Potassium (NPK) nutrients is the third largest consumer of fertilizers in the world (MoP, 2012, p. 12). The annual consumption of NPK nutrients has increased by 62% from 17.4 MT in 2001-02 to 28.1 MT in 2010-11 (PC, 2013, p. 115). The consumption of NPK nutrients per hectare has increased from less than 1 kg in 1951-52 to 106.7 kg in 2005-06 (PC, 2008b, p. 177).

India produces both nitrogenous and phosphatic fertilizers with installed capacity of 12.947 MT nitrogen and 6.201 MT of phosphate. The production of nitrogenous fertilizers is the most energy intensive among all other processes involved in the industry. Ammonia is used as the basic chemical in the production of nitrogenous fertilizers. More than 80% of the ammonia manufactured around the world is used in the production of nitrogenous fertilizers and Urea is the major nitrogenous fertilizers produced in India. The feedstock used for ammonia production is natural gas, naphtha, and fuel oil. Among the feedstock, natural gas-based fertilizers are the most energy efficient, followed by naphtha based fertilizers (MoP, 2012, p. 13).

Iron and Steel

The iron and steel industry has witnessed robust growth with significant increase in both production and consumption over the years. After the economic reforms of 1991 the iron and steel industry went through significant changes. The steel industry removed from the list of industries reserved for Public Sector. In January 1992, price and distribution control have been removed with an objective to make steel industry more efficient and competitive and subsequently restrictions on external trade and, both in import and export also been removed (Ministry of Steel, n.d.[a]). Due to these change there has been a remarkable move towards private sector both at the crude and finished steel stage. Private sector accounted for 67% of the total crude steel production and 74% of total finished steel during 2006-07 as compared to 41% and 54% during 9192-93 respectively (PC, 2008b, p. 188).

India stands 4th in terms of production of crude steel followed by China, Japan, and USA and stands 1st in terms of production of sponge iron or direct reduced iron (Ministry of Steel, n.d.[b]). The industry contributes 2% to the country's GDP and accounts for 6.2% of total industrial production in the country. With a GDP growth of 9% the consumption of the iron and steel sector expected to grow by 10.3% (PC, 2013, p. 112).

The Working Group on steel for the Twelfth FYP has envisaged that the crude steel production capacity in the country is likely to be 140 MT (Ministry of Steel, n.d.[b], p. 44). The National Steel Policy 2012 had projected steel production to reach 275 MT by 2025-26 (The National Steel Policy, 2012, Article 3(4)(b)). The 2012 NTP replaces the National Steel Policy of 2005 and suggests policies to create environment friendly growth of the industry by ensuring sustainable development, achieving efficiency levels at par with the global bests especially in areas such as energy consumption etc. (The National Steel Policy, 2012, Article 3(4)(h)).

Pulp and Paper

The Pulp and Paper industry is one of the 35 high priority industries of India (PC, 2008b, p. 182), produces 10.1 MT of paper per annum and accounts for 2.6% of world's production of paper and paperboard (PC, 2013, p. 122). But it is one of the highly energy intensive and highly polluting sector of the Indian economy and therefore always find place in environmental discussion both at national and international level (Schumacher & Sathaye, 1999).

Following the economic liberalization of 1991, in July 1997 Pulp & Paper industry has been de-licensed allowing 100% Foreign Direct Investment. The yearly turnover of the industry is nearly Rs.35,000 Corers and contributes around Rs.3,000 Corers to the national exchequer. The industry employs approximately 0.37 million people directly and 1.3 million people indirectly (Indian Paper Manufacturers Association, n.d.). The industry can broadly be classified into three segments depending on the raw material they use, namely wood based, agro based and recycled fibre based. Out of 715 mills engaged in manufacturing of pulp, paper and paperboards 25 units are wood based, 139 units are agro based mills and 551 units are recycled fibre based mills (MoP, 2012, p. 17).

The Pulp & Paper industry uses Coal and Electricity as the main source of energy. Other than Coal and Electricity low sulphur heavy stock, furnace oil, light diesel oil, and high speed diesel oil are used for steam generation and captive power generation. The production of Pulp & Paper is highly energy intensive with 75-85% of the energy requirement being used as process heat and 15-25% as electrical power (Schumacher & Sathaye, 1999, p. 8). The energy cost account for 15%-20% of the production costs in India as compared to 10% in USA (MoP, 2012, p. 18). There is significant scope for improving the performance of the Indian Pulp & Paper industry if attention is given to improve Process optimization, waste heat recovery, and cogeneration systems.

Textile

Indian Textile industry is one of the country's oldest industries and has a formidable presence in the economy in terms of output, investment and employment, as it contributes to around 14% of the total industrial production, which accounts for 4% of GDP and 17% of the country's export earnings, 9% of excise collection and 18% of employment in the industrial sector (MoP, 2012, p. 19). There are 1,227 textile mills with a spinning capacity of about 29 million spindles. The Indian textile industry is predominantly cotton based, with about 65% of raw materials consumed being cotton (Dhanabhakyam & Shanti, n.d.). The industry employs around 45 million people and after agriculture, generates second highest number of employment in the country (PC, 2013, p. 123).

The industry has a direct link with the rural economy and production of major fibre crops and crafts such as cotton, wool, silk, handicrafts and handlooms, which in turn employ millions of farmers and crafts persons in rural and semi-urban areas of the country. It has been estimated that one out of every six households in the country depends directly or indirectly on textile sector (Dhanabhakyam & Shanti, n.d., p. 3).

India has a significant presence in the international market in the area of fabrics and yarn. India is the largest exporter of yarn in the international market and has a share of 25% in the world cotton yarn export and accounts for 12% of the world's production of textile fibres and yarn. In terms of spindleage, the Indian textile industry is ranked second, after China, and accounts for 23% of the world's spindal capacity. India posses around 6% of the world rotor capacity and has the highest loom capacity, including handlooms with a share of 61% in world loomage (Dun & Bradstreet India, n.d.).

The energy cost in the textile industry out of the total production cost accounts for 5%–17%. Coal and furnace oil are used for the generation of steam in boilers for process heating applications. The textile mills are making significant efforts towards short and medium term measures.

Thermal Power

Because of steady economic growth of the country, the demand for energy has grown at an average of 3.6% per annum over the past three decades (MoP, 2012, p. 21). India stands 6th in terms of power generation in the world and as of 30th September 2013 the installed generation capacity was 228.72 Giga-watt (GW), out of which thermal power accounts 68.19%. Hydro, Nuclear and Renewable Energy Sources (including small hydro project, biomass gasifier, biomass power and urban and industrial waste power) constitutes 17.39%, 02.08% and 12.32% respectively.

The installed capacity of Thermal Power in India is 155,968.99 Megawatt (MW) Out of the total thermal power generated, Coal based power constitutes 134,388.39 MW, Gas based 20,380.39 and Oil based 1,199.75 MW, which accounts for 58.75%, 08.91% and 0.52% of total installed power generation in the country respectively (MoP, 2013).

Due to competitive tariff advantage over renewable energy projects, coal based and gas based thermal power projects are likely to remain the major source of power generation in the country. The installed generation capacity of thermal power is likely to grow up to 74% by the end of Twelfth FYP (i.e. 2012-2017) and 60% of the thermal capacity planned for the Twelfth FYP are of Supercritical Technology, which is considered to be fuel efficient and environment friendly (INDIA - Power Sector, n.d., p. 2).

After a brief insight in to the 8 energy intensive sectors, it could be very easily realized the level of energy consumption by those sectors and their contribution in countries GDP. With the vision to convert the sectors, those are major contributor to the economy as well as major emitter of GHGs in to sustainable sectors the government planned to initiate market based mechanism. ETS may serve both the regulatory and economic perspective and bring down the overall compliance cost in the country.

ENERGY SECURITY AND SUSTAINABLE DEVELOPMENT

As an emerging economy of the world, India realized that energy is of vital importance for continues development of the nation. India started to think of *Energy Security* for uninterrupted economic development and *Energy Efficiency* for sustainable development.

Renewable Energy and Energy Efficiency Initiatives in India

With the growing concern over country's energy security Renewable Energy and Energy Efficiency was given more significance. After the two oil shocks in 1970s, energy self-sufficiency can be regarded as one of the major factors for growth of Renewable Energy sector, which started to develop since early 1980s in the country (Ministry of New & Renewable Energy [MNRE], n.d.[a]). After attaining a remarkable achievement in the Renewable Energy and Renewable Technology sector, India started to think of changing the way energy is consumed in various sectors of the economy.

Renewable Energy Policy Initiatives

The favourable policies also lead to the growth of renewable energy sector in the country. This sector always received proper attention from the government for its development.

The Electricity Act. 2003

The Electricity Act of 2003 was the first comprehensive framework, which speeded development of renewable energy in the country by providing a developing regulatory structure containing preferential tariffs, Renewable Purchase Obligation (RPO), Renewable Energy Certificate (REC), etc. The Government of India also introduced various alternative combinations of fiscal and financial incentives to promote renewable energy, such as capital and interest subsidy, nil or concessional excise and custom duties in a case to case basis, and generation based incentives or feed-in-tariffs (MNRE, n.d.[b]).

Renewable Energy Certificate

The Renewable Energy Certificates (REC) is a policy mechanism to encourage and incentivise promotion of renewable energy based power generation and with an ultimate objective of facilitating compliance of renewable purchase obligations. The technologies such as wind, solar PV, solar thermal, biomass, hydro etc. are eligible for RECs. The REC mechanism has been introduced in 2010 by the Central Electricity Regulatory Commission (CERC) Regulation (CERC, 2010a & 2010b). The RECs could be traded only at the CERC approved Power exchanges namely, the Indian Energy Exchange Ltd., Delhi (IEX) and the Power Exchange India Ltd., Mumbai (PXIL) within a band of a *floor price* and a *forbearance price* to be determined by the CERC.

As states has varying renewable energy sources, keeping this into mind the CERC has introduced a market based instrument in the form of REC, to facilitate the states to meet their obligation. Therefore the obligation can be met through following ways- *(a) by directly purchasing renewable energy, (b) by generating renewable energy, or (c) by purchasing RECs* (Pandey, 2012).

As per the CERC Regulation 2010, the National Load Despatch Centre has been entrusted as the Central Agency for implementing the REC mechanism and for the registration of the renewable energy generators participating in the scheme, issuance of RECs, maintenance and settlement of REC Account, repository of transactions in REC etc. Around the world REC emerging as the fastest aggregation of non-energy and socially beneficial attributes i.e. environmental and socio-economic attributes. There will be two options available to the renewable energy generators, *(i) either to sell the renewable energy at the preferential tariff fixed by the concerned Electricity Regulatory Commission, or (ii) to sell the electricity* generation *and environmental attributes associated with renewable energy generation separately.* By selecting the latter option, the environmental attributes can be exchanged in the form of RECs which are tradable (Kumar & Agarwala, 2013a).

There are two types of RECs namely *Solar Certificates*, which are issued to eligible entities for generation of electricity based on Solar as renewable energy source and *Non-solar Certificates*, issued to eligible entities for generation of electricity from renewable energy sources other than Solar (CERC, 2010a, Sec.4). The trading of RECs in the country started on March 2011 and as on August 2014 total RECs issued 15,476,160, out of which solar based RECs are and non-solar 383,815 based RECs are 15,092,345. The RECs redeemed so far amounts to 6,645,474, out of which solar RECs are 92,089 and non-solar RECs are 6,553,385 (Renewable Energy Certificate Registry of India, n.d.).

A single REC denomination is issued to the renewable energy generator for 1 MWh electric energy injected into the grid. The RECs issued by the State Commission carries a Unique Certificate Number *inter alia* information regarding name of the issuing body, generator identity, type of generation technology (solar/non-solar), installed capacity of the generator, location of the generator, signature of the authorized person etc (Kumar & Agarwala, 2013b). The RECs remain valid for a period of 730 days after the issuance and no banking and borrowing are allowed (Order in Petition No.266/SM/2012); RECs are valid for a single transfer and no repeated transfer of the same certificate is allowed (Indian Energy Exchange Ltd., n.d.[a]). At the 40th trading session that was closed on 25th June 2014 the price for Solar RECs was around Rs.9300 i.e. USD151 and the price for Non-solar RECs was around Rs.1500 i.e. UDS24 (Climate Connect, 2014).

Renewable Purchase Obligation

The Renewable Purchase Obligation (RPO) means the requirement specified by the concerned State Electricity Regulatory Commission under Section 86(1)(e) of the Electricity Act, 2003, for the obligated entity to purchase electricity from renewable energy sources (CERC, 2010a, Sec.2(m) & The Electricity Act., 2003). Under the RPO scheme each state has to set a state –level target for renewable energy purchase by 'Obligated Entities'. While preparing the RPO regulations, the concerned State Electricity Regulatory Commission has to consider the following factors (Goyel & Jha, 2009):

1. Projections of total quantum of energy required for sale in the State in near future.
2. Total potential for different variants of renewable source of energy in the State.
3. Quantum of energy currently being generated by renewable generators within the State.
4. Commercial impact of renewable power on the retail tariff.
5. Technical impact of renewable energy generator on the state grid.
6. National target as specified by the Central Government policies.

The national target for RPO was set at 5% for 2010, which will increase by 1% annually till it reaches to 15% over a decade's time i.e. by 2020 (Arora et al. 2010, p. 25). There are 27 states out of 29 states (except Arunachal Pradesh and Sikkim), National Capital Territory of Delhi and 6 Union Territories, which have issued RPO/REC regulations and have specified RPO targets (Pratap, Ram & Pathanjali, 2013, p. 20). The state wise data showing targeted RPO could be compared for further reference *Table 3 at APPENDIX*.

The credit for India's success and growth in the field Renewable Energy also goes to its early institutional setups. For the overall development of the renewable sector the Government of India established numerous institutions ranging from technology development, R&D, manpower development to financial institution (Osmani, 2014).

Energy Efficiency Initiatives

Bureau of Energy Efficiency

The urgency and importance of energy saving and energy efficiency can be traced from the Government of India's decision to pass *The EC Act 2001*, which identified 15 large energy intensive sectors called Designated Consumers of the economy and prescribed norms and standard for energy efficiency (Sharma, 2010, p. 377).

The Bureau of Energy Efficiency [The Bureau] has been established on 1st March 2002 under the provisions of *The EC Act, 2001* by merging the Energy Management Centre, a society under the Ministry of power. The Bureau was established with a mission to develop policy and strategies with a thrust on self-regulation and market principles, with the primary objective of reducing the energy intensity of the various sectors of the economy, as per the overall framework of the Energy Consumption Act.

National Mission for Enhanced Energy Efficiency

India is shelter to nearly one-third of the world's poor. Almost 275 million of people are mostly dependent on natural resources and climate fragile sectors for their livelihood. In furtherance to *Bali Action Plan* (UNFCCC, 2007) to meet some of the Climate Change implications under the Nationally Appropriate Mitigation Action (NAMA) principle, India launched the *National Action Plan on Climate Change* (NAPCC) to outline a national long-term strategy to address climate mitigation and adaption in the country.

The plan incorporates a commitment to ensure that *India's per capita GHG emissions level never exceeds than those of the developed countries at* *any point of time in future*. The plan sought to create *balance between the need to maintain steady and higher economic growth in one hand and on the other hand to mitigate and adapt to the effect of the climate change*. Apart from these objectives, the plan also seeks to identify measures that strive to promote development priorities simultaneously addressing the threats posed by climate change, effectively.

On 24th June 2010 the Union Cabinet approved the implementation of the National Mission for Enhanced Energy Efficiency (NMEEE) (Press Information Bureau of India, 2010). *The EC Act, 2001,* provides the basic framework for the implementation of energy efficiency measures. At the Central Government the implementation shall be carried on through the institutional mechanism of the Bureau and through designated agencies at the State level. Various schemes and programmes have been introduced and it is expected that all these initiatives together would result in a saving of 10,000 MW by the end of Eleventh FYP i.e. 2011-12.

To enhance energy efficiency the NMEEE seeks to implement an action plan based on four major initiatives (MoP, 2012) such as:

1. **Perform, Achieve and Trade:** A market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that could be traded.
2. **Market Transformation for Energy Efficiency:** Accelerating the shift to energy efficient appliances in designated sectors through innovative measures to make the product more affordable.
3. **Energy Efficiency Financing Platform:** Creation of mechanisms that would help finance demand side management programmes in all sectors by capturing future energy savings.
4. **Framework for Energy Efficiency Economic Development:** Developing fiscal instruments to promote energy efficiency.

All the schemes and programmes taken together under the National Mission with enhancement in current and on-going programmes would benefit the country in two ways. *Primarily, it would assist the country to adapt to climate change and secondly and most importantly it will set the economy on a path that would progressively and substantially result in mitigation through avoided emission.*

Initially, the development of renewable energy in India started with the idea of energy security and self-sufficiency in energy, poverty elevation through rural electrification and access to electricity for all, which was subsequently combined with the global environmental concern. The early development of institutional setup helped the country to become a world leader in renewable energy and technology. India's present achievement in renewable energy sector has more than three decades old initiatives that started in the early 1980s (Osmani, 2014).

EMISSION TRADING: CONCEPT AND PRACTICE IN INDIA

Global warming issues have been given a serious thought in the recent times and while it has become quintessential to reduce the emission levels, an entirely new industry has emerged having great potential and opportunities for the investors. What was introduced by John Dales, economist from Canada, as tradable rights to control pollution, in 1968, is seemingly lucrative venture and is in vogue for some time now; with carbon credits, green projects, carbon footprints, sustainability reports being off-springs of the initiatives. (Bothra, n.d.)

Evolution and Development

The concept of Emission Trading is an innovative economic idea that had tremendous influence on how governments, international organizations, companies and consumer responds to the challenge of global climate change, emerged in the USA as an alternative to the existing 'command-and-control' and 'pollution taxes' (Meckling, 2011, p. 47).

Environmental endowments are those parts of our existence that we share commonly, such as, atmosphere, air, water, landscapes etc. By the very nature of their commonly shared instinct, market fails to conserve these precious assets as these are public goods, could not be exchanged in markets and therefore no price emerges to signal there relative scarcity. This market failure could be addressed most effectively by providing a price that signals that the environmental endowments in question are scarce in nature (Emission Trading Policy Briefs, n.d.).

The conceptual idea of using economic instrument in environmental policy was coined by the British economist Professor Arthur C. Pigou in 1920, who pointed out the social benefits of forcing companies to pay for the cost of their pollution (Hepburn, 2007). Pigou suggested that the use of emissions fees or taxes as a way to internalize private decisions of environmental costs of pollution (Hanemann, 2009). The tax rate set equal to the marginal external social damage caused by the last unit of pollution at the efficient allocation. Under this tax rate on emissions, firms would internalize the externality and by minimising their own costs, firms would simultaneously minimize the costs to society as a whole (Tietenberg, 2010).

In the year 1960 Ronald Coase came with a contrary opinion than the Pigouvian tax approach and argued that the market could play a substantial role in valuing these rights of environmental endowments by making property rights explicit and transferable. The property rights approach will allow the market to value the property rights to their highest use (Tietenberg, 2010).

Based on the Coase's general theoretical argument the concept of emissions trading as a strategy for controlling pollution was first proposed by Thomas Crocker in 1966 for air pollutants in USA. Croker emphasised on the idea of government setting a cap on aggregate emissions and allowing the market to determine the emission price and the degree of abatement at individual facilities, rather than having the government to set the price through an emission fee unlike the Pigouvian tax approach (Burtraw, Evans, Krupnick, Palmer, & Toth, 2005, p. 2).

In 1968 John Dales explored the idea of emission trading in the case of water pollution in Canada and popularized the concept further. "Crocker and Dales maintained that auctioning of pollution rights would be the best way to arrive at the correct social value of pollution at the desired overall level of pollution" (Meckling, 2011, p. 51). The general properties of controlling pollution anticipated by Crocker and Dales, was further demonstrated formally by Baumol and Oates in 1971. Despite the fact Baumol and Oates's study was not regarding marketable *'permit system'*, rather about a *'charge system'* designed to meet predetermined environmental target. Their study proved that a uniform charge would result in meeting the predetermined environmental target cost effectively.

Finally, W. David Montgomery in 1971 came up with the first mathematical evidence that trading permits could minimize the cost in attaining a predetermined level of pollution reduction target. However Montgomery identified three issues which are critical in designing a tradable permit scheme. These are as such (Tietenberg, 2010, p. 122):

1. Government has to enforce limits on the overall pollution in a geographical area;
2. A mechanism has to be devised for the allocation of permits to individual firms; and,
3. Rules had to be defined clearly for trading of emission rights between the companies.

Today emissions trading can be regarded as the counterpart of a Pigouvian tax on emissions. The primary distinction between tax and an emission trading scheme is that, in the case of a tax, a price per unit emissions is announced by policy-makers, whereas in the case of an emissions trading scheme, an overall amount of allowed emissions is set by policy-makers (Heindl & Löschel, 2012).

There are two different forms of trading permit exists, such as, Baseline-and-Credit and Cap-and-Trade system. In a baseline-and-credit system a baseline emission intensity level is assigned to firms by a regulatory body. The firms that over-comply with the assigned baseline emission intensity level are awarded credits usually called *'emission reduction credits'* and these Emission Reduction Credits may be sold to firms that under-comply the said regulatory standard. Contrary to this, a cap-and-trade system set a limit/cap on aggregate emission by emitting activities/firms and a corresponding number of emission permits are allocated, usually referred as *allowances* either through 'auctioning' or by 'grandfathering' (based on historical emission behaviour). The regulated emitting activities/firms must hold a permit for every unit of emissions made by them.

Emission Trading in Practice

The USA started experimenting with the first generation of emission trading through amendments made to the Clean Air Act in 1977, whereby offsetting was introduced to U.S. environmental policy to achieve both environmental protection and industrial expansion. In the phase-out of leaded gasoline and chlorofluorocarbons (CFC) during 1970s and 1980s emission trading become an option for regions that could not meet the air-quality standards (Meckling, 2011, p. 52).

As scientific consensus emerged during 1980s regarding the link between the occurrence of acid rain and Sulphur Dioxide (SO_2) emitting power plants fuelled by coal and oil, the second generation of emission trading in USA started in the form of Acid Rain Programme with the amendments to the Clean Air Act in 1990. The Acid Rain Programme of the USA is the first nationwide cap-and-trade scheme. The Phase-I and Phase-II of the Sulphur Dioxide trading ran from 1995-99 and 2000-09 respectively (Meckling, 2011, p. 54). The breakthrough for market mechanisms in emission trading came with the Acid Rain Programme, which later become the reference point for ideas of GHGs trading.

Kyoto Protocol: Market Mechanism

The Kyoto Protocol to the UNFCCC was adopted in 1997, which requires developed countries and economies in transition listed in Annex B of the Protocol, to reduce their overall GHG emissions by 5.2% below 1990 levels. The Kyoto Protocol provided for three flexible market based mechanisms that enables the developed countries to meet their emission limitation and reduction commitments (Osmani, 2012).

EU-ETS

The European Union Emission Trading System (EU ETS) is the world's largest mandatory multi-sector international cap-and-trade mechanism that operates in 28 EU member states plus Iceland, Liechtenstein and Norway, all together 31 countries. The EU ETS was launched in 2005 and since then successfully accomplished two phases i.e. Phase-I: 2005-07 and Phase-II: 2008-12 and Phase-III is in operation, started in 2013 and will run up to 2020. The EU ETS covers more than 11,000 energy intensive installations including power station, oil refineries, iron and steel, cement and lime, paper, glass, ceramics and chemicals industries which are responsible for around 45% of the GHG emission within EU (European Commission-Climate Action, n.d.).

India's Very Own Emission Trading Scheme

The National Mission for enhanced Energy Efficiency (NMEEE) mission has a component dealing with market based mechanism to improve energy efficiency in energy intensive large industries and facilities by certification of energy saving, which could be traded. The Ministry of Power and Bureau of Energy Efficiency [The Bureau] are entrusted with the implementation of the mission. The implementation of the mission seeks to promote the effort to create a market for energy efficiency estimated to be around Rs.7400 billion (Rs.74,000 Corore). It is also estimated that by the end of the First PAT cycle, i.e. 2012-13 to 2014-15, about 23 million of oil equivalent will be saved, capacity addition of 19,000 MW will be avoided and 98.55 million tons of CO_2 emission will be reduced (Bureau of Energy Efficiency [BEE], 2011, p. 8).

For effective implementation of energy efficiency in the country the Ministry of Power introduced a company called Energy Efficiency Service Ltd. which shall facilitate in unlocking the market. The Energy Efficiency Service Ltd. (EESL) is a joint venture company of four Central Public Sector Undertakings of Ministry of Power, namely National Thermal Power Corporation Ltd., Power grid Corporation of India Ltd., Power Finance Corporation and Rural Electrification Corporation. The company will promote energy efficiency projects like Bachat Lamp Yojana, Agricultural Demand Side Management and Municipal Demand Side Management. The basic function of EESL is to act as a Resource Centre for capacity building of State Development Agencies, Utilities, Financial Institutions etc. It is a very unique company of its kind in entire South Asia and amongst a very few around the world which is exclusively for implementation of energy efficiency (Press Information Bureau of India, 2009 & Energy Efficiency Service Ltd., n.d.).

The flagship of the NMEEE mission is the PAT mechanism, is a market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through Energy Saving Certificates (ESCerts) which could be traded. The ESCerts will be traded on special trading platforms which are to be created in the two power exchange namely the Indian Energy Exchange Ltd., Delhi and the Power Exchange India Ltd., Mumbai (BEE, 2011, p. 9). The intention of the Central Government is to establish a ESCerts trading system is to encourage facilities/industries with lower cost mitigation options to over-comply and sell those excess certificates to those facilities/industries with high cost mitigation options (Jue, Davis, Vanamali & Houdashelt, n.d., p. 9). The scheme mandates specific energy consumption reduction targets to designated consumers (DCs) notified under *The EC Act, 2001*, which collectively accounts for 25% of the GDP and consumes around 45% of the commercial energy of the country (Kossoy & Guigon 2012, p. 101).

On 4th July 2012, Mr. Sushil Kumar Shinde, Minister for Power, Government of India officially inaugurated the *Perform, Achieve and Trade Scheme* in New Delhi (The Economic Times, 2005). The Ministry of Power had released the list of 478 designated consumers through the Gazette Notification dated 30th March 2012. In exercise of its power conferred by clause (g) and Clause (h) of Section 14 of *The EC Act of 2001*, the Government of India in consultation with, The Bureau specifies the norms and standards for the period from 2012-13 to 2014-15 in relation to their current level of energy consumption, being the baseline energy consumption norms and standard. Through this notification, established under the PAT Rules (The Energy Conservation Rules, 2012), the Central Government referred the designated consumers to comply with the energy consumption norms and standards specified against each industry by the target year 2014-15

(The Energy Conservation Notification, 2012). With this historic notification India entered into a new era, started its very own *cap-and-trade* scheme for energy efficiency.

The Table 2 shows that, as per Section 14(e) of the Act the Ministry of Power on 2nd march 2007 has notified 9 industrial units and other establishments which are consuming energy more than the threshold namely Aluminium, Cement, Chlor-Alkali, Fertilizer, Iron and Steel, Pulp & paper, Thermal Power Plant and Railways and set norms and standards for them (BEE, 2011, p. 9). Except Railways the remaining 8 sectors are automatically required to participate in the First cycle of PAT scheme. The Railways (diesel loco sheds and workshops) are having 8 designated consumers as per the notification of the Ministry of Power. But these 8 designated consumers were excluded from the First cycle of PAT scheme because the sectorial energy scenario and energy usage pattern is under study by The Bureau (BEE, 2011, p. 13).

Table 2. Minimum annual energy consumption and estimated number of Designated Consumers (DCs)

Sl. No.	Sectors	Minimum Annual Energy Consumption for the DCs (Tonnes of Oil Equivalent)	No. of DCs
1.	Aluminium	7500	10
2.	Cement	30000	85
3.	Chlor-alkali	12000	22
4.	Fertilizer	30000	29
5.	Iron and steel	30000	67
6.	Pulp and paper	30000	31
7.	Textile	3000	90
8.	Thermal power plant	30000	144
Total		172500	478

*The Railways is not included.

Source: (MoP, 2012 & The Energy Conservation Notification, 2007b)

The designated consumers of these 8 sectors account for annual energy consumption of about 231 mMTOE (million metric tons of oil equivalent) as per data recorded in 2007-08 which is around 54% of the total energy consumed in the country (BEE, 2011, p. 13).

The baseline of Specific Energy Consumption would be calculated according to the details of production and annual consumption since 2005-06 to 2009-10 submitted as per the mandatory notified form of the Act (BEE, 2011, p. 17). The designated consumers who achieve the target reduction from the baseline Specific Energy Consumption during the cycle of three years shall be issued ESCerts. The number of Energy Saving Certificates to be issued will depend on the quantum of energy saved at the target year and the value of the ESCerts would be based on the crude oil price, calculated according to the provisions of the PAT Rules (The Energy Conservation Rules, 2012, Rule-16: Specification of value of energy).

There are penalties for non-compliance. If an industry fails to achieve the set target, it will be penalized for the same. The penalty will be calculated on the basis of what remained to be achieved to meet the target and the figure will be multiplied by the present day cost of energy in oil equivalent. The director of the Bureau said that 'as each industry will be competing against itself only, it will have its energy consumption in 2010 as its baseline data, to improve upon' (Paliwal, 2012).

Amendment to the EC Act, 2001

To make the PAT market mechanism scheme stronger and effective the Central Government made certain major amendments in *The EC Act 2001*. The new Section 14A, Power of Central Government to issue Energy Saving Certificate has been added to the Act. Under the provision of the Section 14A(1) the Government of India may issue ESCerts to the designated consumers whose energy consumption is less than the prescribed norms and standard. As per the Section 14A(2), the designated consumers, whose energy consumption is more than the prescribed norms and standard shall be entitled to purchase ESCerts to comply with prescribed norms and standard (The EC (Amendment) Act, 2010, Sec. 7).

The Section 30 of the principle Act has been substituted, where by the Appellate Tribunal established under Section 110 of *The Electricity Act* (The Electricity Act, 2003) shall, without prejudice to the provisions of the said Act, be the Appellate tribunal for the purpose of this EC Act. and here appeals against the orders of the adjudicating officer or the Central Government or the State Government or any other authority under this Act. (The EC (Amendment) Act, 2010, Sec. 9). Accordingly the words "under this Act", of Section 110 of the Electricity Act is also substituted by the words "under this Act or any other law for the time being in force" (The EC (Amendment) Act, 2010, Sec. 16).

Apart from widening the scope of The Act by affiliating the provisions of Appellate tribunal of The Electricity Act for dispute redressal, to ensure the compliance of the market based PAT mechanism the penalties were enhanced further. For the Section 26(1) of the principal Act the words *'Ten thousand rupees'* and the words *'One thousand rupees'* has been substituted by the words *'Ten lakh rupees'* (one million) (The EC (Amendment) Act, 2010, Sec. 8 (a)(ii): Amendment of sec. 26(1)) and *'Ten thousand rupees'* (The EC (Amendment) Act, 2010, Sec. 8 (a)(iii): Amendment of sec 26(1)) respectively. Where a designated consumer fails to comply with the provisions of Clause (n) of Section 14 i.e. norms and standard, shall be liable to a penalty which shall not exceed *rupees one million* and in the event of continuing failure there shall be additional penalty which shall *not be less than the price of every metric tonne of oil equivalent of energy*, prescribed under this Act, i.e. in excess of the prescribed norms (The EC (Amendment) Act, 2010, Sec. 8(b)).

The Act further says, if any amount payable under section 26(2) and if not paid, may be recovered as if it were an arrear of land revenue (The EC Act, 2001, Chapter-Vlll, Penalties & Adjudication), which makes it more stringent. Treating a non payment as an arrear of land revenue makes it very difficult for the defaulter to avoid their liability in respect of any non-compliance. Because once pronounced as arrear of land revenue, automatically procedures for seizure and attachment of assets of such defaulter will follow.

Pat Implementation Process

For the successful implementation of Perform, Achieve and Trade mechanism the EC Act has put in place certain compliance requirements for the Designated Consumers, failure to which leads to penalty. Broadly the compliance requirement could be categorised as follows:

Compliance Requirement

1. **Mandatory Reporting:** Every DCs has to furnish report/scheme to the Designated Authority for implementation of efficient use of energy and its conservation.[1]
2. **Appointment of Energy Manager:** Every DCs shall designate or appoint an Energy Manager who will be in charge of activities for energy efficiency measures and its conservation and reporting to the Designated Authority.[2]
3. **Monitoring and Verification:** The Designated Energy Auditors shall conduct auditing of energy consumption by DCs as per norms and standard set by the Act and manners and intervals of time specified by regulations.[3]
4. **Energy Efficiency Norms and Standard:** Comply with the Specific Energy Consumption norms and standard prescribed by the Act (The EC Act, 2001, Sec. 14 (n) & The EC Rules 2012).

Penalty for Non-Compliance

1. **Penalty:** At the event of failure to comply with the following provisions DCs shall be liable to a penalty not exceeding *rupees one million* (Rs.1,000,000) and in case of continuing failure there shall be, additional penalty up to the extent of *rupees ten thousand* each day. The provision are as such where the Central Government by notification or in consultation with the Bureau:
    a. Prohibit manufacture or sale or purchase or import of equipment or appliance specified under Section 14(b) unless such equipment or appliances conforms to energy consumption standards (The EC Act, 2001, Sec. 14 (c));
    b. Direct display of such particulars on label on equipment or on appliance specified under Section 14(b) and in such manner as may be specified by regulations (The EC Act, 2001, Sec. 14 (d));
    c. Direct, having regard to quantity of energy consumed or the norms and standards of energy consumption specified under Section 14(a) the energy intensive industries specified in the Schedule to get energy audit conducted by an accredited energy auditor in such manner and intervals of time as may be specified by regulations (The EC Act, 2001, Sec. 14 (h));
    d. Direct, if considered necessary for efficient use of energy and its conservation, any designated consumer to get energy audit conducted by an accredited energy auditor (The EC Act, 2001, Sec. 14 (i));
    e. Direct any designated consumer to furnish to the designated agency, in such form and manner and within such period, as may be prescribed, the information with regard to the energy consumed and action taken on the recommendation of the accredited energy auditor (The EC Act, 2001, Sec. 14 (k));
    f. Direct any designated consumer to designate or appoint energy manger in charge of activities for efficient use of energy and its conservation and submit a report, in the form and manner as may be prescribed, on the status of energy consumption at the end of the every financial year to designated agency (The EC Act, 2001, Sec. 14 (l));
    g. Direct every owner or occupier of the building or building complex, being a designated consumer to comply with the provisions of energy conservation building codes for efficient use of energy and its conservation (The EC Act, 2001, Sec. 14 (r));
    h. Direct, any designated consumer referred to in clause (r) of Sec. 14, if considered necessary, for efficient use of energy and its conservation in his building to get energy audit conducted in respect of such building by an accredited energy auditor in such manner and intervals of time as may be specified by regulations (The EC Act, 2001, Sec. 14 (s));
    i. Direct every owner or occupier of a building or building complex being a designated consumer to comply with the provisions of the energy conservation building codes (The EC Act, 2001, Sec. 15);
    j. Direct, if considered necessary for efficient use of energy and its conservation, any designated consumer referred to in clause (b) to get energy audit conducted by an accredited energy auditor in such manner and at such intervals of time as may be specified by regulations (The EC Act, 2001, Sec. 15 (c));

k. Direct, any designated consumer to furnish to the designated agency, in such form and manner and within such period as may be specified by rules made by it, information with regard to the energy consumed by such consumer (The EC Act, 2001, Sec. 15 (h));

2. **Penalty:** At the event of failure to comply with the provision of specific energy consumption 'Norms & Standard' (The EC Act, 2001, Sec. 14(n)), DCs shall be liable to a penalty which shall not exceed *rupees one million* (Rs.1,000,000) and in the event of continuing failure there shall be additional penalty which shall *not be less than the price of every metric tonne of oil equivalent of energy*, prescribed under this Act, i.e. in excess of the prescribed norms.

Successful Compliance

- **Energy Saving Certificates:** The Energy Saving Certificates (ESCerts) shall be issued to the DCs whose energy consumption is less than the set norms and standard. However, the DCs, whose energy consumption is excess can purchase ESCerts to comply with prescribed norms and standards (The EC (Amendment) Act, 2010, Sec. 7: Insertion of Sec. 14A (2)). One EScert is equivalent to 1 Million Tonne of Oil Equivalent. In the ESCerts trading system banking is allowed for two consecutive cycles (Indian Energy Exchange Ltd., n.d.[b]).

Likely Impact on the Industries

The Perform, Achieve and Trade market mechanism policy will prove to be a good carrot-stick approach with incentives for compliance and penalties for non-compliance. It will certainly be difficult for the energy intensive sectors; those were included in the present PAT cycle, to cope up with the energy threshold while maintaining the growth. Again this will also be difficult for a country like India, which is passing through economic crisis and also sees itself as an economic super power in waiting. It will surely be a challenge for India to maintain a steady, respectable growth of GDP while considering the environmental aspect of climate change, global warming and GHG mitigation.

But recognizing the fact of strong policy and regulatory framework, it is presumed that in the long run all the major energy intensive sectors of the economy will adapt to energy efficiency measures while contributing towards a steady economic growth.

However, the policy will demonstrate India's seriousness to achieve the common objective of climate change mitigation at the international level and adaption to a low-carbon economy at the national level.

CONCLUSION

In conclusion it could be said that, energy is vital for the growth and existence of any country and for a developing country it's even more important. India, being a developing economy adopted policies for energy security and energy efficiency by giving more importance to renewable energy and by introducing market based mechanism for emission trading. The market mechanism had been introduced with two main objectives primarily, to meet the inefficiencies in the large energy intensive sectors of the economy in a cost effective manner, which will turn the energy intensive sectors into energy efficient sectors. Secondly and most importantly, it will help the country to reduce overall GHG emissions from its core industrial sectors.

The country had already achieved significant success in the field of renewable energy with its existing policies of energy security and energy efficiency. As per the GHG Inventory of 1994, out of total estimated 250 MT of direct CO_2 emissions from the industry, approximately 60% were due to energy use by the industries. Because of effective policies and their implementations India has achieved remarkable success. The GHG emissions intensity of the country's GDP declined by more than 30% during the period 1994-2007. So there remains further possibility of reducing GHG emission by making industries more efficient.

The REC mechanism was introduced with an intention to give a push to energy generation from renewable sources, whereas, ESCerts intended to promote energy saving and technology upgradation. To carry forward the objective India introduced Perform, Achieve and Trade emission trading market mechanism and setting up a strict compliance regime by enhancing the penalties for non-compliance with the Amendment Act of 2010 and to treat the non-payment of penalty at the event of default, if any as an arrear of land revenue, to make it more effective. It is also estimated that by the end of the First Perform, Achieve and Trade cycle, about 23 million of oil equivalent will be saved, capacity addition of 19,000 MW will be avoided and 98.55 million tons of CO_2 emission will be reduced.

This initiative will certainly reduce the country's dependence on imported source of energy, gradually reducing the huge gap between energy production and consumption and finally, will help India to realize its commitment to reduce GHG emissions. However the effectiveness of PAT mechanism can only be evaluated in its entirety after the First Compliance period (i.e. 2012-13 to 2014-15) comes to an end.

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KEY TERMS AND DEFINITIONS

Banking: Refers to the use of RECs, ESCerts or any other allowances at a later compliance period/cycle instead of the present compliance period/cycle.

Borrowing: Refers to the use of RECs, ESCerts or any other allowances from a future compliance period/cycle to fulfil the obligation of the present compliance period/cycle.

Designated Consumer: Considering any consumer's intensity and quantity of energy consumption, the amount of investment required for switching over to energy efficient equipments, capacity of industry to invest for the same and also availability of energy efficient machinery and equipments required by the industry referred as designated consumer.

Floor Price: The minimum price as determined by the Central Electricity Regulatory Commission in accordance with the regulations, at and above which the RECs can be dealt in the power exchanges.

Forbearance Price: The ceiling or maximum price as determined by the Central Electricity Regulatory Commission in accordance with the regulations, within which only the RECs can be dealt in the power exchanges.

ENDNOTES

1 *The Energy Conservation Act 2001, Section 14(k)* – "The Central Government may, by notification, in consultation with the Bureau, direct any designated consumer to furnish to the designated agency, in such form and manner and within such period, as may be prescribed, the information with regard to the energy consumed and action taken on the recommendation of the accredited energy auditor". *See also The Energy Conservation Rules 2012, The Energy Conservation Rules, 2007* and *The Energy Conservation Rules, 2008*

2 *The Energy Conservation Act, 2001, Section 14(l)* – "The Central Government may, by notification, in consultation with the Bureau, direct any designated consumer to designate or appoint energy manager in charge of activities for efficient use of energy and its conservation and submit a report, in the form and manner as may be prescribed, on the status of energy consumption at the end

of the every financial year to designated agency."

See also The Energy Conservation Notification, 2007a.

3 *The Energy Conservation Act, 2001: Section 14(h)* – "The Central Government may, by notification, in consultation with the Bureau, direct, having regard to quantity of energy consumed or the norms and standards of energy consumption specified under clause (a) the energy intensive industries specified in the Schedule to get energy audit conducted by an accredited energy auditor in such manner and intervals of time as may be specified by regulations." and *Section 13(2)(q)* – "The Bureau may perform such functions and exercise such powers as may be assigned to it by or under this Act and in particular, such functions and powers include the function and power to, specify, by regulations, the manner and intervals of time in which the energy audit shall be conducted." *See* also *The Energy Conservation Rules 2012* and *The Bureau of Energy Efficiency Regulation, 2010.*

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APPENDIX

Table 3. Status of State wise RPO obligations in India[4]

	State	Year of Issue/Regulation	State Agency	Technology Type	RPO Trajectory							
					FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
1	Andhra Pradesh	The APERC-Renewable Power Purchase Obligation (Compliance By Purchase Of Renewable Energy/ Renewable Energy Certificates) Regulations, 2012 (Regulation 1 of 2012)	State Load Despatch Centre of Andhra Pradesh	Non-solar	--------	--------	4.75	4.75	4.75	4.75	4.75	--------
				Solar	--------	--------	0.25	0.25	0.25	0.25	0.25	--------
				Total	--------	--------	5.00	5.00	5.00	5.00	5.00	--------
2	Assam	The AERC (Renewable Purchase Obligation and its Compliance) Regulations, 2010 (No. AERC/21/2010)	Assam Energy Development Agency	Non-solar	1.35	2.70	4.05	5.40	6.75			
				Solar	0.05	0.10	0.15	0.20	0.25			
				Total	1.40	2.80	4.20	5.60	7.00			
3	Bihar	The BERC (Renewable Purchase Obligation, its Compliance and REC Framework Implementation) Regulations, 2010 (BERC-Regl-01/10–05)	Bihar Renewable Energy Dev. Agency	Non-solar	1.25	2.00	3.25	3.50	3.75			
				Solar	0.25	0.50	0.75	1.00	1.25			
				Total	1.50	2.50	4.00	4.50	5.00			
4	Chhattisgarh	The CSERC (Renewable Purchase Obligation and REC framework Implementation) Regulations, 2011 (No. 36/CSERC/2011)	Chhattisgarh Renewable Energy Agency	Non-solar	4.75	5.00	5.50	--------				
				Solar	0.25	0.25	0.50	--------				
				Total	5.00	5.25	5.75*	--------				
5	Delhi	The DERC (Renewable Purchase Obligation and Renewable Energy Certificate Framework Implementation) Regulations, 2012 (No: F.3(292)/Tariff/DERC/2010-11/3026)	Energy Efficiency & Renewal Energy Management Centre	Non-solar	--------	--------	3.25	4.60	5.95	7.30	8.65	
				Solar	--------	--------	0.15	0.20	0.25	0.30	0.35	
				Total	--------	--------	3.40	4.80	6.20	7.60	9.00	
6	JERC (Goa & UTs)	The Joint Electricity Regulatory Commission for state of Goa & Union Territories (Procurement of Renewable energy) Regulations, 2010 (No.: JERC-14/2010)	• The Member Secretary, Goa Energy Dev. Agency • Dev. and Planning Officer, Administration of DNH • Principal Scientific Officer Department of Science and Technology Daman	Non-solar	0.75	1.70	2.60	--------				
				Solar	0.25	0.30	0.40	--------				
				Total	1.00	2.00	3.00*	--------				
7	Gujarat	The Gujarat Electricity Regulatory Commission (Procurement of Energy from Renewable Sources) Regulations, 2010 (Notification No.3 of 2010)	Gujarat Energy Dev. Agency (GEDA)	Non-solar	4.75	5.50	6.50	--------				
				Solar	0.25	0.50	0.50	--------				
				Total	5.00	6.00	7.00*	--------				
8	Haryana	The Haryana Electricity Regulatory Commission (Terms & Condition for determination of Tariff from Renewable Energy Sources, RPO & REC) Regulation, 2010 (No. HERC/23/2010)	Haryana Renewable Energy Dev. Agency (HREDA)	Non-solar	1.25	1.50	2.25	--------				
				Solar	0.25	0.50	0.75	--------				
				Total	1.50	2.00	3.00	--------				

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Table 3. Continued

	State	Year of Issue/Regulation	State Agency	Technology Type	RPO Trajectory							
					FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
9	Himachal Pradesh	The Himachal Pradesh Electricity Regulatory Commission (Renewable Power Pm-chase Obligation and its Compliance) (First Amendment) Regulations, 2011 (No. HPERC/438)	Directorate of Energy, Govt. of H. P.	Non-solar	--------	10.00	10.00	10.00	10.00	11.00	12.00	13.00
				Solar	--------	0.01	0.25	0.25	0.25	0.25	0.25	0.50
				Total	--------	10.01	10.25	10.25	10.25	11.25	12.25	13.50
10	Jammu & Kashmir	The J&KSERC (Renewable Power Purchase Obligation, its compliance and REC frame work implementation) Regulations, 2011 (No: JKSERC/10)	• J & K State Power Dev. Corporation • Jammu & Kashmir Energy Dev. Agency • Ladakh Renewable Energy Dev. Agency • Kargil Renewable Energy Dev. Agency	Non-solar	0.98	2.90	4.75	--------				
				Solar	0.02	0.10	0.25	--------				
				Total	1.00	3.00	5.00	--------				
11	Jharkhand	The Jharkhand State Electricity Regulatory Commission (Renewable purchase obligation and its compliance) Regulations, 2010 (No. 28)	Jharkhand Renewable Energy Dev. Agency (JREDA)	Non-solar	1.75	2.50	3.00	--------				
				Solar	0.25	0.50	1.00	--------				
				Total	2.00	3.00	4.00	--------				
12	Kerala[5]	The Kerala State Electricity Regulatory Commission (RPO and its Compliance) Regulations, 2010 (No. 1517/CT/2010/ KSERC)	Agency for Non-conventional Energy & Rural Technology (ANERT), Trivandrum	Non-solar	2.75	3.05	3.35	3.65	3.95	4.25	4.55	4.85
				Solar	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
				Total	3.00	3.30	3.60	3.90	4.20	4.50	4.80	5.10
13	Madhya Pradesh	The Madhya Pradesh Electricity Regulatory Commission (Cogeneration and Generation of Electricity from Renewable Sources of Energy) Regulations, 2010 (No.3042/ MPERC-2010)	MP Urja Vikas Nigam Ltd.	Non-solar	0.80	1.90	3.40	5.30	6.00			
				Solar	--------	0.40	0.60	0.80	1.00			
				Total	0.80	2.50	4.00	5.50	7.00			
14	Maharashtra	The Maharashtra Electricity Regulatory Commission (Renewable Purchase Obligation, its compliance and REC framework Implementation) Regulations, 2010 (No. MERC/Legal/2010/483)	Maharashtra Energy Dev. Agency (MEDA)	Non-solar	5.75	6.75	7.75	8.50	8.50	8.50		
				Solar	0.25	0.25	0.25	0.50	0.50	0.50		
				Total	6.00	7.00	8.00	9.00	9.00	9.00		
15	Manipur[6]	The Joint Electricity Regulatory Commission for the States of Manipur & Mizoram (RPO and its Compliance) Regulations, 2010 (No. H.13011/5/09-JERC)	Manipur Renewable Energy Dev. Agency (MANIREDA)	Non-solar	1.75	2.75	4.75	4.75				
				Solar	0.25	0.25	0.25	0.25				
				Total	2.00	3.00	5.00	5.00				
16	Mizoram[3]	The Joint Electricity Regulatory Commission for the States of Manipur & Mizoram (RPO and its Compliance) Regulations, 2010 (No. H.13011/5/09-JERC)	Zoram Energy Dev. Agency (ZEDA)	Non-solar	4.75	5.75	7.75	8.75				
				Solar	0.25	0.25	0.25	0.25				
				Total	5.00	6.00	7.00	9.00				

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Table 3. Continued

	State	Year of Issue/Regulation	State Agency	Technology Type	RPO Trajectory							
					FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
17	Meghalaya	The Meghalaya State Electricity Regulatory Commission (Renewal Energy Purchase Obligation and its Compliance) Regulations, 2010 (NO.MSERC/05/61)	Meghalaya Non-Conventional & Rural Energy Dev. Agency (MNREDA)	Non-solar	0.30	0.45	0.60					
				Solar	0.20	0.30	0.40					
				Total	0.50	0.75	1.00					
18	Nagaland	The Nagaland Electricity Regulatory Commission (Renewable Purchase Obligation and its Compliance) Regulations, 2011 (No. NERC/REGN/2011)	Department of New & Renewable Energy, Nagaland	Non-solar	5.75	6.75	7.75					
				Solar	0.25	0.25	0.25					
				Total	6.00	7.00	8.00					
19	Odisha	The OERC (Renewable and Co-generation Purchase Obligation and its Compliance) Regulations, 2010 (No.OERC-Engg-02/2010)	Orissa Renewable Energy Dev. Agency (OREDA	Non-solar	4.50	4.90	5.35	5.80	6.25	6.70		
				Solar	--------	0.10	0.15	0.20	0.25	0.30		
				Total	4.50	5.00	5.50	6.00	6.50	7.00		
20	Punjab	The Punjab State Electricity Regulatory Commission (RPO & its compliance) Regulations, 2011 (No. PSERC/Secy./Reg./55)	Punjab Energy Dev. Agency (PEDA)	Non-solar		2.37	2.83	3.37	3.81			
				Solar		0.03	0.07	0.13	0.19			
				Total		2.40	2.90	3.50	4.00			
21	Rajasthan[7]	The Rajasthan Electricity Regulatory Commission (REC & RPO Compliance Framework) Regulations, 2010 (No.RERC/Secy/Reg. 82)	Rajasthan Renewable Energy Corporation	Non-solar	--------	5.50	6.35	7.20	7.50	8.20	8.90	
				Solar	--------	0.50	0.75	1.00	1.50	2.00	2.50	
				Total	--------	6.00	7.10	8.20	9.00	10.20	11.40	
22	Tamil Nadu[8]	The Tamil Nadu Electricity Regulatory Commission (Renewable Energy Purchase Obligation) Regulations, 2010 (Notification No. TNERC/RPO/ 19/1)	State Load Dispatch Centre of Tamil Nadu	Non-solar	--------	8.95	8.95	8.95	8.95	8.95		
				Solar	--------	0.05	0.05	0.05	0.05	0.05		
				Total	--------	9.00	9.00	9.00	9.00	9.00		
23	Tripura	The Tripura Electricity Regulatory Commission (Procurement of Energy from Renewable Sources) Regulations, 2010 (No. F.25/TERC/2009/415)	Tripura Renewable Energy Dev. Agency (TREDA)	Non-solar	--------	0.90	0.90	1.90				
				Solar	--------	0.10	0.10	0.10				
				Total	--------	1.00	1.00	2.00				
24	Uttarakhand[9]	The UERC (Compliance of Renewable Purchase Obligation) Regulations, 2010 (No.F-9(21)/RG/UERC/2010/1422)	Uttarakhand Renewable Energy Dev. Agency (UREDA)	Non-solar	4.00	4.50	5.00	6.00	7.00	8.00	9.00	11.00
				Solar	--------	0.025	0.05	0.05	0.075	0.10	0.30	0.50
				Total	4.00	4.525	5.05	6.05	7.075	8.10	9.30	11.50
25	Uttar Pradesh	The Uttar Pradesh Electricity Regulatory Commission (Promotion of Green Energy through RPO) Regulations, 2010 (No. UPERC/Secy/Regulation/10 - 787)	Uttar Pradesh New and Renewable Energy Dev. Agency (UPNEDA)	Non-solar	3.75	4.50	5.00					
				Solar	0.25	0.50	1.00					
				Total	4.00	5.00	6.00*					

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Table 3. Continued

	State	Year of Issue/Regulation	State Agency	Technology Type	RPO Trajectory							
					FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
26	West Bengal[10]	The West Bengal Electricity Regulatory Commission (Procedure for Accreditation of a Renewable Generation Project for REC Mechanism) Regulations, 2013 (No. 51/ WBERC)	State Load Dispatch Centre of West Bengal	Non-solar	--------	--------	--------	3.90	4.35	4.80	5.25	5.30
				Solar	--------	--------	--------	0.10	0.15	0.20	0.25	0.30
				Total	--------	--------	--------	4.00	4.50	5.00	5.50	6.00
27	Karnataka	The Karnataka Electricity Regulatory Commission (Procurement of Energy From Renewable Sources) Regulations, 2011 (Notification No. S/03/1)	State Load Dispatch Centre (SLDC)	2011-12 onwards	ESCOM		Non-solar		Solar		Total	
					BESCOM MESCOM CESC		9.75		0.25		10.00	
					HESCOM GESCOM Hukkeri Society		6.75		0.25		7.00	

*The RPO specified for the Financial Year 2012-13 shall be continued beyond 2012-13 till any revision is effected by the Commission

Section 12
Policy and Innovation

Chapter 28
Does Fiscal Policy Influence Per Capita CO_2 Emission?
A Cross Country Empirical Analysis

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ABSTRACT

Encouraging economic activities is a major motivation for countries to disburse subsidies, but such transfers may also lead to sustainability and climate change related concerns. Through a cross-country empirical analysis involving 131 countries over 1990-2010, the present analysis observes that higher proportional devolution of budgetary subsidies lead to higher CO_2 emissions. The results demonstrate that structure of economy is a crucial determinant for per capita CO_2 emission, as countries having higher share in agriculture and services in GDP are characterized by lower per capita CO_2 emission and vice versa. The empirical findings also underline the importance of the type of government subsidy devolution on CO_2 emissions. Countries having high tax-GDP ratio are marked by lower per capita CO_2 emission, implying that government budgetary subsidy is detrimental for environment whereas tax is conducive for sustainability. The analysis underlines the importance of limiting devolution of subsidies both in developed and developing countries.

1. INTRODUCTION

Providing subsidies to local players is a time-tested policy instrument, which can be applied for responding to various motives, e.g., countering domestic distortions (Bhagwati and Ramaswami, 1963), for granting 'infant-industry' protection (Melitz, 2005), for facilitating innovation, supporting national champions as a part of the long term industrial policy, ensuring redistribution, etc. (Howse, 2010; WTO, 2006). A country may extend subsidies to their primary, manufacturing and service sectors through various channels, e.g., through input subsidies (e.g. per unit fuel subsidy), output subsidies (e.g. per unit price support) and 'regulatory reliefs' in terms of maintaining weaker

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environmental regulatory standards and tax reliefs (Barde and Honkatukia, 2004; Heutel and Kelly, 2013; Fisher-Vanden and Ho, 2007).

Existence of subsidies *per se* does not necessarily lead to adverse environmental consequences. For instance, carefully crafted subsidy policies can contribute significantly for ensuring environmental protection in an economy (e.g. subsidies for promoting organic farming or other forms of environment-friendly agriculture, technology upgradation support to industry for securing lower emissions, promotion of renewable energy etc.). Nevertheless, the adverse environmental implications of subsidies are well documented in existing literature. On one hand, several environmental implications of input subsidies have been underlined (Heutel and Kelly, 2013). First, demand for any subsidized input is expected to witness an increase due to substitution of other non-subsidized inputs. Second, firms enjoying the benefits of the subsidized inputs tend to produce more due to the fall in per unit production expenses, which increases their demand for all inputs in general. As a result of the consequent change in input usage patterns, the sectors benefiting from input subsidies generally grows in size and their expanded scale of operation might lead to over-production and in turn over-exploitation of resources. On the other hand, if the government provides output subsidies by offering higher price per unit of output produced to the producers, the chain of events again may potentially result in over-use of inputs, over-exploitation of resources, over-production and consequent environmental degradation (van Beers and van den Bergh, 2001). The existing literature supports this contention by underlining that subsidies generally encourage overuse of dirty inputs and enable the environmentally inefficient producers to continue in the market (Barde and Honkatukia, 2004). Conversely reduction of subsidies enhance environmental sustainability by lowering pollution-causing capital accumulation, shifting of capital and labor to less pollution intensive firms and enhancing the output of more productive firms (Bajona and Kelly, 2012).[1]

In addition to the existing theoretical and empirical literature, the subsidy-environment linkage has received considerable attention in the regulatory forums as well. For instance, the adverse environmental implication of subsidies in general, and energy subsidies, which encourage greater use of fossil fuels in particular, is well recognized in the UN discussion forums. It is estimated that world emissions of CO_2 and Green House Gases (GHGs) can be reduced by 13 and 10 percent respectively by 2050 with the removal of fossil fuels and electricity subsidies in 20 non-OECD countries (Burniaux et al., 2009). One major objective of the Kyoto Protocol negotiations has been to secure reduction of subsidies, which lead to GHGs emissions (UNEP, 2003). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) noted that, "Direct and indirect subsidies can be important environmental policy instruments, but they have strong market implications and may increase or decrease emissions, depending on their nature" (IPCC, 2007). A similar spirit has subsequently been echoed in the Rio+20 Conference declaration as well, "We remain focused on achieving progress in addressing a set of important issues, such as, *inter alia*, trade-distorting subsidies and trade in environmental goods and services" (UNCSD, 2012). However, the UN initiatives for reduction of fuel subsidies have till date achieved limited success so far (Keen, 2012; IMF, 2013). One underlying reason is that the provisions under Kyoto Protocol, "does not specify the policies that states must use to achieve the bound emission reductions, or the relative desirability of different policy instruments" (Howse, 2010). In other words, the participating countries are expected but not strictly compelled to reduce the harmful subsidies being provided to their domestic players.

In addition to the United Nations Environment Programme (UNEP) initiatives, the multilateral trade forums under the wings of World Trade Organization (WTO) have also attempted to curb adoption of subsidies, although from a different standpoint. Subsidies are considered to be detrimental to the fair trade principle, which is cornerstone of the WTO architecture. Therefore the objective of the ongoing negotiations under the Agreement on Subsidies and Countervailing Measures (ASCM) is to bring about better discipline on both direct financial transfers as well as revenue foregone (e.g. interest payment on loan restructuring, tax breaks). One major objective of the ASCM negotiations is to classify the existing and future subsidies in Member countries under two broad categories, namely, *actionable* (i.e. subsidies which are directly linked with production and hence trade-distorting) and *non-actionable* (i.e. subsidies which are not directly linked with production and hence are less trade-distorting). While the subsidies falling under the former category attracts immediate notice and countervailing duties by the partner countries, the latter category measures are considered relatively innocuous.

While the major focus of the WTO negotiations revolve around the question of trade-distortion, greater discipline on subsidies are also associated with tangible environmental benefits. For instance, eliminations of subsidies by China in its bid to join the WTO were more fruitful in reducing emissions as compared to tariff reforms (Bajona and Kelly, 2012). Along similar lines, currently ASCM and other subsidy related negotiations under WTO (e.g. fisheries subsides, amber box subsidies in agriculture) are geared for lowering the provision of actionable subsidies by the Member countries, which in addition to being trade-distorting subsidies might also potentially be environmentally damaging ones (Chakraborty et al., 2011; Mukherjee et al., 2014). Nevertheless, the subsidy reforms under WTO have achieved limited results so far, given the slow progress of the Doha Round negotiations (Anderson et al., 2008; Morgan, 2010), which is a matter of grave concern. Identifying the scenarios where the actionable subsidies can influence the sustainability scenario, Howse (2010) notes:

The "market" into which subsidies to address climate change are intervening is one that has historically been pervasively distorted by subsidies, including fiscal advantages, provided to producers and consumers of (greenhouse gas–emitting) fossil fuels. It is also a market in which existing networks for the distribution and retailing of energy—whether electricity grids or chains of service stations—have been largely designed to favour fossil fuels. In addition, subsidies schemes and tax systems have often, apart from distorting choices among energy sources, led to a reduction in incentives for energy efficiency in that they relieve users from paying the full marginal cost of an additional unit of energy.

Experiences of a number of WTO disputes reveals that provision of subsidies to the local players in the energy sector and climate change related concerns may not be completely unrelated. On the other hand, subsidization initiatives to further environmental objectives may turn out to be *actionable* at times. In fact, domestic supports extended to aid the search for renewable energy has emerged as a major area of trade discord in recent period. For instance, the discussions witnessed in the *Canada — Certain Measures Affecting the Renewable Energy Generation Sector* (WTO Dispute No. 412, complaint by Japan) and *China — Measures concerning wind power equipment* (WTO Dispute No. 419, complaint by US) indicate in that direction (Bougette and Charlier, 2014; Kent, 2013). The growing instances of such disputes have initiated discussions on the necessity for the relaxing WTO rules on green subsidies (Charnovitz, 2014).

The less than desired pace of subsidy reforms across countries and the growing concerns over climate change, as reflected through GHGs emissions, calls for a deeper analysis to identify whether there exists any linkage between the two. In this context, the current analysis intends to explore the statistical relationship between country-wise devolution of budgetary subsidies and transfers and per capita CO_2 emissions in the global canvas. The current analysis is restricted only to the per capita CO_2 emission as an indicator of climate change owing to limited availability of long time series data on other GHGs for a large number of countries. The time period for the analysis is 1990-2010, which also covers 131 countries. The objective of the empirical analysis is to understand how provision of budgetary subsidies and transfers influence climate change concerns across development groups.

The present analysis intends to contribute to the existing pool of literature on subsidy-climate change nexus in two ways. First, a large body of studies in the theoretical as well as empirical literature have adopted general equilibrium framework, data envelopment analysis (DEA) etc. to analyze the impacts of subsidy on environment and climate change (Bajona and Kelly, 2012; Heutel and Kelly, 2013; Managi, 2010, Yagi and Managi, 2011). However, empirically explaining the relationship between government budgetary subsidies and per capita CO_2 emissions in a cross country panel data framework is a relatively less researched area. The current paper bridges this gap by testing the statistical relationship between the two series. In addition, the present analysis particularly contributes to the literature by attempting to understand the influences of various government subsidy reporting standards on CO_2 emission patterns.

Second, the existing theoretical and empirical literature explains the climate change related repercussions of international trade flows with help of three effects (WTO-UNEP, 2009; Zhang, 2012; Chakraborty and Mukherjee, 2014). First, through *scale effect* the growing output and exports of the polluting sectors may adversely influence environment, as that may cause additional energy use and exploitation of natural resources (Cole and Elliott, 2003). As subsidies are often provided for enhancing exports (Afonso and Silva, 2012; Bailey, 2002; Defever and Riaño, 2012; Girma *et al.*, 2009; Mansor and Karim, 2012), this effect may lead to serious climate change concerns. Secondly, trade can lead to change in industry structure and output composition resulting from *composition effect*, which may or may not always be adverse in nature (Honma and Yoshida, 2011). If output from the polluting manufacturing sectors rise, then the potential for emissions of pollutants also goes up. Clearly, if the subsidy (in the form of input, output or fuel subsidy) creates a bias in favour of a polluting sector, this effect might dominate. Finally, with rise in income level, environmental governance is expected to improve in an economy - through adoption of better pollution abatement technologies, formulation and enforcement of stricter regulatory policies etc. In other words, the growing income may create a demand for lower emissions and the associated reforms will be determined by the *technique effect* (Cole and Elliott, 2003). If the allocated subsidies are earmarked for adoption of greener production methods and secures access to technology upgradation, this effect is likely to overshadow the former two effects. Since a considerable proportion of subsidies until the recent period has been provided in the countries with certain underlying trade objectives (WTO, 2006), the empirical analysis intends to capture how their influence is reflected on these three effects.

The present analysis is arranged along the following lines. First, the existing literature on subsides and their potential implications on climate change concerns are briefly discussed. Second, selection of the empirical model and the data sources for the analysis is explained, followed by an account of the macro trends observed in the principal variables. A panel data empirical analysis is conducted in the following section for identifying the influence of budgetary subsidies on per capita CO_2 emissions. Finally, based on the empirical results, a few policy conclusions are drawn.

2. SUBSIDY AND CLIMATE CHANGE CONCERNS: EVIDENCE FROM LITERATURE

One major effect of subsidies is to insulate market prices of natural resources from the full social costs of production. The consequent reduction in per unit cost aided by subsidies often influence choice of production techniques resulting in over-production and thereby facilitating overexploitation of natural resources and / or uses of energy, and subsequently deepening of climate change concerns (Halkos and Paizanos, 2013; Lopez *et al*., 2011; Porter, 1997; van Beers and van den Bergh, 2001). Similar subsidy-led adverse environmental impacts are often rampant in several resource-intensive sectors, namely, primary sector (e.g. agriculture, fisheries), transport, energy and water sector etc. (van Beers et al., 2007; Myers and Kent, 2001; Maddison et al., 1997; Myers, 1998; WTO, 1999, 2009). The net emissions of GHGs from agricultural activities may get influenced by the existing crop management system (Samarawickrema and Belcher, 2005).

Support extended to the local agriculture sector through input subsidies (e.g., irrigation, electricity / fuel, fertilizer and pesticide subsidy) often leads to over-production and consequent overexploitation of natural resources (e.g., groundwater) and biodiversity loss, as the support incentivizes their overuse by lowering per unit variable costs for the farmers (Heutel and Kelly, 2013). Evidences on interrelationship between fertilizer usage in OECD countries and their CO_2 emission levels deserves mention here (Atici, 2009). Such fertilizer subsidies are particularly helpful for the bigger farmers, given their scale advantage, which may bear further environmental repercussions (Abimanyu, 2000). Similarly, provision of electricity subsidy reduces per unit cost of irrigation and facilitates cultivation of water-intensive crops, which are by nature also fertilizer and pesticide intensive (Mukherjee, 2010). Such subsidies often leads to groundwater overexploitation on one hand (Sidhu, 2002) and large scale leaching of nitrates and pesticides into aquifers on the other (Mukherjee, 2012; Kushwaha, 2008). Fuel subsidies provided to fishing trawlers and other vessels for capturing marine fisheries similarly lead to overuse of mineral fuels, harmful discharge in seas and over-fishing (Sharp and Sumaila, 2009; Sumaila *et al*., 2008).

Output subsidies result into higher than market price for domestic farmers through price support measures and other similar policies, thereby creating a push for greater cropping intensity and volume of agricultural production (Pasour and Rucker, 2005). Intensive cropping pattern leads to environmental concerns like groundwater depletion and soil pollution (Scherr, 2003); conversion of forests, rainforests, and wetlands into cultivable lands (OECD, 2003; WTO, 1999) and diversion of water resources (Myers and Kent, 2001). Similarly, the fisheries subsidies in the form of price support results in increasing fishing intensity, causing overexploitation of the fish stocks (Porter, 2000). In other words, both input and output subsidies lead to serious environmental as well as climate change related concerns.

Apart from input and output subsidies, government supports encouraging land use change patterns often result into climate change concerns (Naughton-Treves, 2004). Such change in land use pattern in often undertaken for augmenting agricultural production by converting forests and wetlands into farmlands for cultivating foodgrains or cash crops (Lopez, 1997; WTO, 1999). Through a cross-country empirical analysis, Galinato and Galinato (2013) have shown that rise in government spending is associated with increasing forest land clearing for agricultural production. While in the short run such change results in higher CO_2

emissions, the long run consequences include decline in steady-state forest biomass and further rise in CO_2 emissions. van Solinge (undated) noted the implications of granting mineral and mining rights, particularly oil exploration rights, in Amazonian rainforest.

Along similar lines, subsidies offered to the manufacturing and energy sector often result in equally harmful environmental consequences (UNCSD, 2012). For instance, fossil fuel subsidies contribute particularly to air pollution, emissions of GHGs and loss of biodiversity, as they reduce the operational cost of recipient industries and leads to higher volume of fossil fuel burning. Such energy-related and other form of subsidies have emerged as major problems in developed countries (Victor, 2009), emerging economies (UNEP, 2008; WTO, 2006) and leading Asian economies like China (Chow, 2007; Haley, 2008; Heutel and Kelly, 2013) and South Korea (Kang, 2012). Such energy subsidies, once in place, are difficult to repel as the political economic compulsions faced by the government may not favour their removal. Commenting on continuance of fuel subsidies, UNEP (2008) notes:

The beneficiaries will always have an interest in defending that subsidy when their gains exceed their share of the economic or environmental costs. The resistance to cutting subsidies can be very strong. Moves to ration heavily subsidised gasoline in Iran in 2007 led to serious civil unrest. Similarly, massive demonstrations and rioting over fuel-price increases brought down the Indonesian national government in 1998.

While budgetary subsidies play a crucial role in influencing the climate change concerns, the role of implicit subsidies (e.g., income foregone) are no less important (IPCC, 2007). As compared to budgetary subsidies which are generally reported in Government Budgets, implicit subsidies are difficult to identify but their magnitude could often surpass the budgetary subsidy by many times and create strong *composition effects* (Srivastava and Rao, 2002). Evidence from the literature reveals that final consumption subsidies (direct and/or indirect) provide perverse incentives to households for overconsumption and results in environmental damage – e.g. Eastern Europe and Central Asian countries provide direct energy subsidies to energy providers to keep the household tariff below the actual cost of production (Laderchi et al., 2013). Moreover, implicit subsidies provided to Mexican industries in terms of below market price for petroleum fuels resulted in 5.7 percent increase in energy intensity between 1970 and 1990, as compared to decrease in energy intensity by 35.3 percent in OECD industry (Kate, 1993). However, subsidies provided for purchasing environmentally friendly goods is also available in some countries (Toshimitsu, 2010). It has been reported that subsidized crop insurance policies result in expansion of agriculture in marginal quality (economically inferior and environmentally vulnerable) land, which is environmentally detrimental (LaFrance *et al.*, 2001). Another manifestation of this phenomenon is that as China provides capital subsidy by offering interest on borrowed capital below the market rate, the flat carbon tax system fails in protecting welfare by reducing emissions (Fisher-Vanden and Ho, 2007). A system of progressive carbon tax regime instead is desirable in an economy, which receives subsidies. Moreover, adoption of weaker environmental standards on pollution abatement functions as implicit cost subsidies to producers eventually leading to environmental degradation (Templet, 2003; Kelly, 2009; Barde and Honkatukia, 2004). Weaker pollution monitoring for Chinese state owned enterprises has been reported in the literature (Dasgupta et al., 2001b), that functions as an implicit subsidy for the operating units. While estimated values of sector-specific input subsidies is available for select countries for certain years, one major challenge is however to obtain actual / estimated data on implicit subsidies at country level on a regular basis.[2]

Given the data limitation on implicit subsidies, the primary objective of the present analysis is to analyze the nexus between government budgetary subsidies and climate change concerns as reflected through per capita CO_2 emissions. However, the per capita CO_2 emissions at country level may also be influenced by variables other than budgetary subsidies. To account for their influences a few control variables have been included in the present analysis in line with the existing literature on environmental sustainability, namely: past values of the per capita CO_2 emissions, Per Capita GDP (PCGDP in current US $),share of agricultural, manufacturing and service sectors in GDP, and level of urbanization in an economy. The income level of a country is generally positively related with its environmental sustainability (Bruvoll and Medin, 2003; de Bruyn et al., 1998; Mukherjee and Kathuria, 2006; Copeland and Taylor, 2004), since growing income level leads to a demand for cleaner environment. However, the Environmental Kuznets Curve Hypothesis (EKCH) notes that as an economy moves from primary to secondary sector, with deforestation and rise in industrial activities higher emissions may be witnessed (Galinato and Galinato, 2012). In addition, with further rise in development level, the contribution of the services sector rises in an economy and environmental sustainability improves (Shafik, 1994; Selden and Song, 1994; Grossman and Krueger, 1995; Mukherjee and Chakraborty, 2009). Hence, in addition to the PCGDP, the square term of it has also been incorporated in the model for understanding the effect of the higher order terms. Next, given the fact that the manufacturing sector is one of the major contributors of GHGs, the share of the manufacturing sector in GDP has been considered as one of the control variables. The effect of the other two sectors, namely, agriculture and services are also used as control variables in the regression analysis. Collection of tax revenue as percentage of GDP has also been incorporate in the model.[3] Finally, level of urbanization (proxied through percentage of urban population in total population) has been included in the model as a control variable as growth divergence may bear interesting climate change repercussions (Maiti and Agrawal, 2005; Sahibzada, 1993). A robustness check has also been undertaken for the analysis.

3. EMPIRICAL MODEL

The following panel data regression model is estimated here for 131 countries over 1990-2010 for analyzing the effect of budgetary subsidies on per capita CO_2 emission:

$$log(CO_{2it}) = \alpha + \beta_1 log\,(SUB_{it}) + \beta_2\, log\,(SUB_{i(t-1)}) + \beta_3\, log\,(CO_{2i(t-1)}) + \beta_4\, log\,(PCGDP_{it}) + \beta_5\, log\,(PCGDP_{it})^2 + \beta_6\, log\,(AGRIGDP_{it}) + \beta_7 log\,(MFGGDP_{it}) + \beta_8\, log\,(SERVGDP_{it}) + \beta_9\, log(TAXREV_{it}) + \beta_{10}\, log(URB_{it}) + C_{it} + GOV_{it} + T_t + \varepsilon_{it} \quad (1)$$

where,

log or prefix l represents the logarithmic transformation of the variables.

α represents the constant term.

βs *are coefficients.*

CO_{2it} represents Per Capita CO_2 emission (in tonne per annum) of country *i* for year *t*.

$CO_{2i(t-1)}$ represents Per Capita CO_2 emission (in tonne per annum) of country *i* for year *t – 1*.

SUB_{it} represents budgetary subsidy (as percentage of GDP) provided by country *i* for year *t*.

$SUB_{i(t-1)}$ represents budgetary subsidy (as percentage of GDP) provided by country *i* for year *t-1*.

$PCGDP_{it}$ represents per capita GDP (current US $) of country *i* for year *t*.

$AGRIGDP_{it}$ represents agriculture value added (expressed as percentage of GDP) of country *i* for year *t*.

$MFGGDP_{it}$ represents manufacturing value added (expressed as percentage of GDP) of country *i* for year *t*.

$SERVGDP_{it}$ represents services, etc. value added (expressed as percentage of GDP) of country *i* for year *t*.

$TAXREV_{it}$ represents tax revenue (as percentage of GDP) of country *i* for year *t*.

URB_{it} represents the level of urbanization (urban population expressed as percentage of Total population) in country *i* in year *t*.

C_{it} represents the Cash dummy in country *i* in year *t* (takes the value of 1 if the country follows cash accounting method, and 0 if the country follows accrual accounting system).

GOV_{it} is a government financing dummy in country *i* in year *t* [takes the value of 1 if the subsidy corresponds to General Government (GG), and 0 for Budgetary Central Government (BCG) or Central Government (CG)].

$PCGNI_{it}$ represents per capita nominal Gross National Income (US Dollars at current prices and current exchange rates) of country *i* for year *t*-.

LIC represents the low income country (PCGNI: US$1,035 or less) dummy, which has a value of 1 for the corresponding countries and 0 otherwise.

LMIC represents the lower-middle income country (PCGNI: U$1,035 - 4,085) dummy, which has a value of 1 for the corresponding countries and 0 otherwise.

UMIC represents the upper-middle income country (PCGNI: US$4,085 - 12,615) dummy, which has a value of 1 for the corresponding countries and 0 otherwise.

HIC represents the high income country (PCGNI: US$12,616 or more) dummy, which has a value of 1 for the corresponding countries and 0 otherwise.

T_t represents the time dummies (i.e., T_1=1 for 2000 and 0 otherwise).

ε_{it} represents the disturbance term.

The advantage of using the log-linear model in the current context is that the estimated coefficients can be interpreted as the elasticity between budgetary subsidy and per capita CO_2 emission and other variables.

The independent variables included in the proposed empirical model are in line with the existing empirical literature, especially in terms of measuring the aforesaid three effects. First, the literature notes that higher volume of output might be associated with higher emission of pollutants owing to factors like additional energy use, exploitation of natural resources etc. Hence $PCGDP_{it}$ has been considered here as the proxy of the *scale effect*. Second, as per predictions of the EKCH in the early stages of development a country moves from primary to secondary (i.e. manufacturing) sector, leading to increase in emissions level. Given the EKCH empirical evidence and the fact that the manufacturing sector is one of the major contributors of GHGs, $MFGGDP_{it}$ has been considered as the proxy of the *composition effect* in the present context. Thirdly, the EKCH also notes that further development may be associated with greater sustainability with rise in contribution of relatively less polluting services sectors, higher citizen demand for cleaner environment, adoption of better environmental governance through stricter enforcement of sustainable practices etc. Therefore, $PCGDP^2_{it}$, $SERVGDP_{it}$ and URB_{it} have been included in the present model as the proxies of the *technique effect*.

4. DATA SOURCES AND MACRO TRENDS

The present analysis obtains the data on budgetary subsidies from Government Finance Statistics (GFS).[4] It is observed that GFS reports the government subsidy figures for countries according to the level government for which required information is available. There are three levels of government reporting have been observed in the GFS database for which the required data on subsidy is available. First, the *General Government* (GG) includes all the Central Government (CG) transfers plus budgetary expenses of all the Central Ministries / Departments and the same for the State Governments (SG) (including provincial or regional) and Local Governments. The *Central Government* (CG) transfers on the other hand represent the consolidated transfers of the Central Government (including transfers of Central Ministries / departments). Finally, subsidies reported under *Budgetary Central Government* (BCG) covers "Any central government entity that is fully covered by the central government budget" (IMF, 2005). In addition, the GFS generally reports the budgetary statistics for countries adopting *cash accounting* method, but for several countries *accrual (non-cash) accounting* method has been reported. When data is available for a country for different level of government, preference is given to GG over CG and similarly CG over BCG.

IMF provides the data on subsidy under the broad head of 'Government and Public Sector Finance' as per the guidelines of *Government Finance Statistics Manual 2001*.[5] Under the specified accounting method (cash and non-cash or accrual), for a particular level of government the data on subsidies and transfers to public corporations and private enterprises is available under the heading 'Expenses by Economic Type' and sub-heading 'Expense'. The present analysis considers the data on subsidies as percentage of GDP of respective countries and the process scale out the size of the economy (as measured by their respective GDP). As per *GFS Manual 2001*, the IMF reported data on subsidies are, "…current transfers that government units pay to enterprises either on the basis of the levels of their production activities or on the basis of the quantities or values of the goods or services that they produce, sell, or import. Included are transfers to public corporations and other enterprises that are intended to compensate for operating losses" (IMF, 2005). In order to understand the differential effects of the data reporting differences in methods of accounting and the level of government, two dummy variables, namely, C_{it} and GOV_{it}, have been included in the empirical models.

The subsidies considered in the current analysis include only direct budgetary subsidies provided by general government, central government or budgetary central government of a country. The indirect or implicit subsidies (i.e., income foregone in terms of tax rebate / exemptions etc.) are not covered due to non-availability of consistent cross-country data on that front. The effect of subsidies is estimated by considering per capita annual emission of CO_2 (in metric tonne) as an indicator of climate change impact in a country. The per capita CO_2 data is obtained from World Development Indicators database (World Bank, 2013).

For the control variables, the data on per capita GDP, share of agriculture, manufacturing and services sectors in GDP, level of urbanization and tax revenue (as percentage of GDP) have been taken from World Development Indicators database. The data on TAXREV is also obtained from WDI. The dummy variables have been generated from the obtained data series as per the defined specifications.

The emerging trends in the major series considered in the regression analysis, namely – budgetary subsidies, per capita CO_2 emissions, per capita GDP, share of the three sectors in GDP, tax revenue as a percentage of GDP, level of urbanization etc. are illustrated with their descriptive statistics summarized in Table 1. First, it is observed that while a fluctuating trend is being noticed for both the average budgetary subsidies expressed as percent of GDP and per capita CO_2 emission, a rise has been noted in the former series. Similarly, average share of agriculture and manufacturing sectors have declined over the period, while the same for the services sector is showing a rising trend. A rise in tax revenue as a percentage of GDP and level of urbanization has also been noticed.

The observation from Table 1 calls for having a closer look at the subsidy-emission patterns prevalent at the countries at different levels of

Table 1. Descriptive Statistics for the Key variables included in the Regression Model for Selected Countries

	Average Per Capita CO2 Emission (in Tonne)	Average Budgetary Subsidy (% of GDP)	Average Per Capita GDP (current US $)	Average Share of Agriculture in GDP (%)	Average Share of Manufacturing in GDP (%)	Average Share of Services in GDP (%)	Tax Revenue (as % of GDP)	Urban Population (as % of Total Population)
1990	3.96 ± 5.45	1.76 ± 2.32	5426 ± 8045	18.88 ± 14.82	17.23 ± 8.34	49.3 ± 13.66	14.54 ± 7.83	51.5 ± 23.65
	(0.02 - 26.2)	(0.01 - 14.38)	(161 - 36337)	(0.62 - 61.55)	(2.93 - 39.17)	(15.9 - 81.04)	(1.55 - 39.6)	(6.27 - 99.76)
1991	4.01 ± 5.7	1.55 ± 1.32	5538 ± 8276	18.51 ± 14.96	17.38 ± 9.1	50.3 ± 14.43	14.55 ± 7.62	51.81 ± 23.61
	(0.05 - 36.43)	(0 - 6.11)	(168 - 36310)	(0 - 64.07)	(1.72 - 45.28)	(18.01 - 79.79)	(0.26 - 41.68)	(6.46 - 99.79)
1992	4.55 ± 6.48	1.75 ± 2.15	5830 ± 8830	18.47 ± 15.54	17.42 ± 9	50.69 ± 14.77	14.94 ± 7.58	52.11 ± 23.57
	(0.04 - 54.74)	(0.01 - 11.79)	(110 - 39230)	(0 - 68.88)	(1.68 - 43.54)	(17.58 - 80.85)	(0.09 - 42.88)	(6.65 - 99.82)
1993	4.55 ± 6.98	1.37 ± 1.35	5569 ± 8386	18.48 ± 15.87	16.58 ± 8.01	51.66 ± 14.73	15.53 ± 8.22	52.42 ± 23.54
	(0.04 - 62.44)	(0.01 - 5.99)	(80 - 39721)	(0 - 65.12)	(1.6 - 36.14)	(19.43 - 82.86)	(1.09 - 46.6)	(6.84 - 99.85)
1994	4.48 ± 6.83	1.31 ± 1.21	5913 ± 9007	18.07 ± 15.47	16.49 ± 7.69	52.05 ± 14.35	15.37 ± 7.98	52.72 ± 23.52
	(0.04 - 61.04)	(0.01 - 5.26)	(65 - 43555)	(0 - 65.86)	(2.27 - 39.03)	(18.15 - 84.03)	(1.42 - 47.33)	(7.02 - 99.9)
1995	4.67 ± 7.18	1.3 ± 1.16	6773 ± 10293	18.04 ± 16.09	16.25 ± 7.37	52.59 ± 14.69	17.25 ± 8.87	53.03 ± 23.5
	(0.04 - 61.51)	(0.01 - 5.84)	(65 - 50593)	(0 - 81.82)	(2.31 - 39.06)	(12.91 - 85.3)	(1.15 - 57.8)	(7.21 - 100)
1996	4.74 ± 7.17	1.52 ± 1.31	6956 ± 10292	17.78 ± 15.9	16 ± 7.24	52.65 ± 15	17.03 ± 8.69	53.29 ± 23.46
	(0.05 - 62.1)	(0 - 6.08)	(73 - 49681)	(0 - 93.98)	(2.2 - 37.83)	(4.14 - 85.84)	(0.97 - 55.8)	(7.42 - 100)
1997	4.77 ± 7.54	1.41 ± 1.3	6802 ± 9715	17 ± 15.19	15.77 ± 7.26	53.27 ± 14.68	16.85 ± 8.72	53.55 ± 23.42
	(0.05 - 68.53)	(0.01 - 8.03)	(125 - 44140)	(0 - 76.95)	(2.22 - 39.46)	(8.24 - 85.73)	(1.17 - 53.58)	(7.63 - 100)
1998	4.7 ± 6.89	1.32 ± 1.35	6783 ± 9742	16.73 ± 15.12	15.65 ± 7.21	54.44 ± 14.14	16.43 ± 8.6	53.82 ± 23.39
	(0.05 - 58.87)	(0 - 7.39)	(129 - 45565)	(0 - 78.64)	(2.24 - 39.34)	(11.84 - 84.49)	(1.49 - 59.37)	(7.83 - 100)
1999	4.66 ± 6.63	1.46 ± 1.33	7107 ± 10238	16.01 ± 14.89	15.39 ± 7.48	54.51 ± 14.75	16.61 ± 7.52	54.08 ± 23.37
2000	4.72 ± 6.85	1.28 ± 1.1	7130 ± 10073	14.88 ± 14.3	15.13 ± 7.76	54.98 ± 15.44	16.84 ± 7.51	54.34 ± 23.35
	(0.04 - 58.5)	(0 - 6.95)	(92 - 46453)	(0 - 76.07)	(1.44 - 38.67)	(3.35 - 87.54)	(1.63 - 39.32)	(8.25 - 100)
2001	4.7 ± 6.2	1.41 ± 1.47	7029 ± 9881	14.63 ± 14.17	15.03 ± 7.51	56.06 ± 15.02	16.37 ± 7.54	54.65 ± 23.31
	(0.03 - 49.63)	(0 - 8.42)	(97 - 45743)	(0 - 77.42)	(2.02 - 39.68)	(4.26 - 88.33)	(1.04 - 40.46)	(8.47 - 100)
2002	4.67 ± 6.02	1.54 ± 1.66	7461 ± 10606	14.64 ± 14.27	14.8 ± 7.44	56.13 ± 15.15	16.05 ± 7.11	54.95 ± 23.28
	(0.02 - 45.23)	(0 - 9.22)	(111 - 50583)	(0 - 80.07)	(2.06 - 39.19)	(4.92 - 89.07)	(1.18 - 41.15)	(8.7 - 100)

continued on following page

Table 1. Continued

	Average Per Capita CO2 Emission (in Tonne)	Average Budgetary Subsidy (% of GDP)	Average Per Capita GDP (current US $)	Average Share of Agriculture in GDP (%)	Average Share of Manufacturing in GDP (%)	Average Share of Services in GDP (%)	Tax Revenue (as % of GDP)	Urban Population (as % of Total Population)
2003	4.92 ± 6.69	1.63 ± 1.65	8735 ± 12631	14.36 ± 13.99	14.91 ± 7.48	56.36 ± 15.24	16.66 ± 8.06	55.25 ± 23.26
	(0.02 - 54.76)	(0.01 - 9.08)	(108 - 64532)	(0 - 73.48)	(2.14 - 39.88)	(5.31 - 89.86)	(1.32 - 56.54)	(8.92 - 100)
2004	5.04 ± 7.12	1.68 ± 1.65	10023 ± 14455	13.77 ± 13.19	15.04 ± 7.44	56.65 ± 15.14	16.8 ± 8.44	55.55 ± 23.24
	(0.03 - 61.62)	(0.02 - 8.21)	(122 - 74389)	(0 - 66.12)	(2.09 - 39.56)	(3.81 - 90.51)	(0.23 - 60.41)	(9.15 - 100)
2005	5.04 ± 7.2	1.79 ± 1.7	10934 ± 15608	13.27 ± 13.23	14.65 ± 7.24	56.97 ± 15.21	17.39 ± 8.56	55.85 ± 23.23
	(0.02 - 63.18)	(0 - 8.16)	(133 - 80925)	(0 - 67.01)	(2.01 - 38.93)	(2.96 - 91.26)	(0.18 - 60.77)	(9.38 - 100)
2006	5.1 ± 6.96	1.73 ± 1.69	11871 ± 16805	12.98 ± 12.93	14.61 ± 7.43	57.34 ± 14.48	18.15 ± 9.47	56.17 ± 23.19
	(0.02 - 58.64)	(0 - 9.51)	(158 - 90016)	(0 - 63.82)	(0 - 41.35)	(20.54 - 91.72)	(0.12 - 63.52)	(9.63 - 100)
2007	5.19 ± 7.2	1.77 ± 1.86	13594 ± 19136	12.64 ± 12.73	14.72 ± 7.29	57.92 ± 14.47	18.45 ± 9.45	56.49 ± 23.16
	(0 - 58.35)	(0 - 9.46)	(163 - 106920)	(0 - 65.6)	(1.85 - 41.72)	(22.43 - 92.76)	(0.2 - 65.9)	(9.88 - 100)
2008	5.07 ± 6.66	2.17 ± 2.2	14980 ± 20658	12.44 ± 12.94	14.49 ± 7.33	58.35 ± 14.36	18.27 ± 8.45	56.81 ± 23.13
	(0.01 - 50.03)	(0 - 10.33)	(187 - 112029)	(0 - 67.26)	(1.73 - 42.23)	(18.91 - 92.69)	(0.28 - 58.69)	(10.14 - 100)
2009	4.84 ± 6.25	1.97 ± 2.14	12931 ± 17628	12.47 ± 13.08	13.73 ± 7.08	59.77 ± 14.25	16.95 ± 6.24	57.13 ± 23.11
	(0.01 - 42.27)	(0 - 9.63)	(185 - 100541)	(0 - 58.19)	(1.47 - 42.27)	(24.38 - 92.83)	(0.97 - 34.91)	(10.39 - 100)
2010	5 ± 6.44	1.91 ± 2.04	13716 ± 18555	11.69 ± 12.01	13.44 ± 6.87	59.98 ± 14.23	17.01 ± 6.08	57.45 ± 23.09
	(0.01 - 40.31)	(0 - 9.57)	(211 - 103574)	(0 - 57.3)	(0.87 - 35.62)	(20.79 - 92.84)	(0.94 - 34.28)	(10.64 - 100)

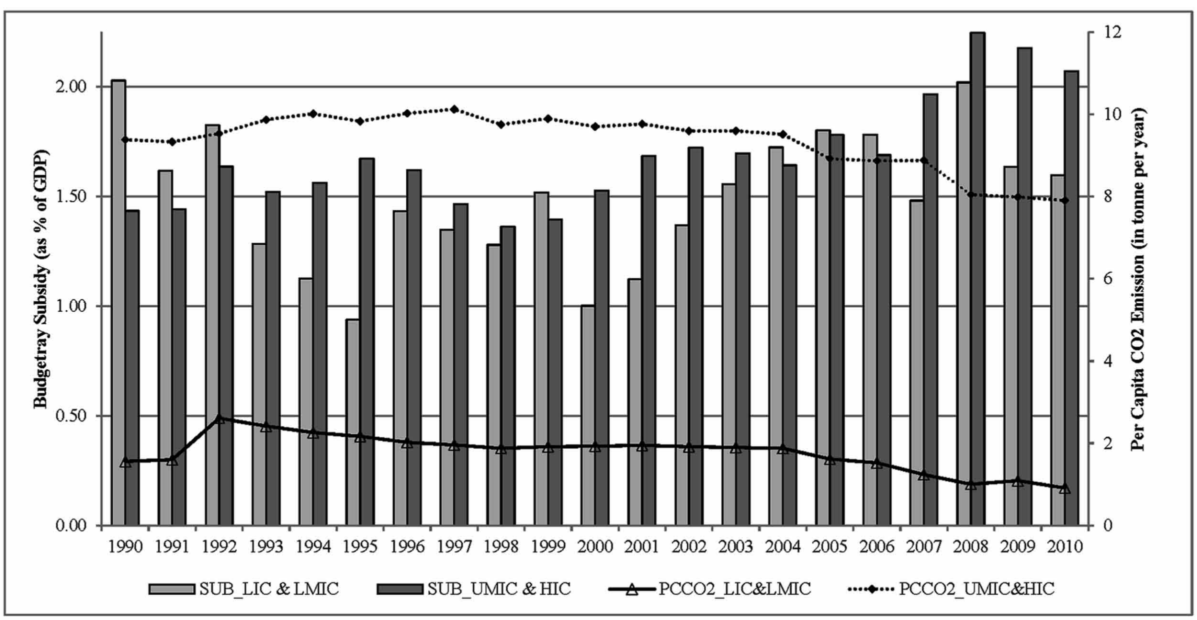
Notes: Figures in the parenthesis show the range for the corresponding average value, figure after ± is the Standard Deviation.
Source: Compiled by authors from various sources

development. To analyze that, the sample countries are classified into four broad groups based on their Per Capita Gross National Income (PCGNI), as defined earlier.[6] In order to understand the subsidy-climate change concerns across country groups, first the two data series are simultaneously considered in Figure 1. For the ease of presentation, the LIC and LMIC countries are grouped together whereas UMIC and HIC countries are considered as another separate group. It is revealed from the values displayed in the figure that the higher income countries are generally characterized by both high degree of budgetary subsidies and per capita CO_2 emissions.

With the help of Figure 2 the devolution of budgetary subsidy patterns (as % of GDP) across the four groups of countries is analyzed next. A fluctuating trend is noticed across all the groups, barring the exception of the UMIC. Fluctuations have understandably been more pronounced both for the LIC owing to their limited fiscal space. Interestingly in the post-2001 period, the average budgetary subsidy devolution as percentage of GDP for LMIC countries is found to be higher than the same for the HIC countries. However, in the post-2007 period the figure has sharply increased for the HIC and UMIC as compared to their LMIC counterparts, underlining the provision of budgetary subsidies there in the post-recession period.

Figure 3 finally shows the average annual per capita CO_2 emissions pattern across the four groups of countries. The development-led divergence becomes all the more obvious from the trends observed in the figure, which illustrates that average emissions have been considerably higher in richer economies as compared to their lower income counterparts. Moreover, the figure shows that for developed countries average per capita

Figure 1. Temporal Variations of Average Budgetary Subsidy (as percentage of GDP) and Average Per Capita CO_2 Emission (in tonne per year) across Country Groups
Note: figure is based on average values of the variables across sample countries
Source: Constructed by authors



Note: Figure is based on average values of the variables across sample countries
Source: Constructed by the authors

Figure 2. Average Annual Budgetary Subsidy (% of GDP) across Development Groups
Source: Constructed by authors from GFS data

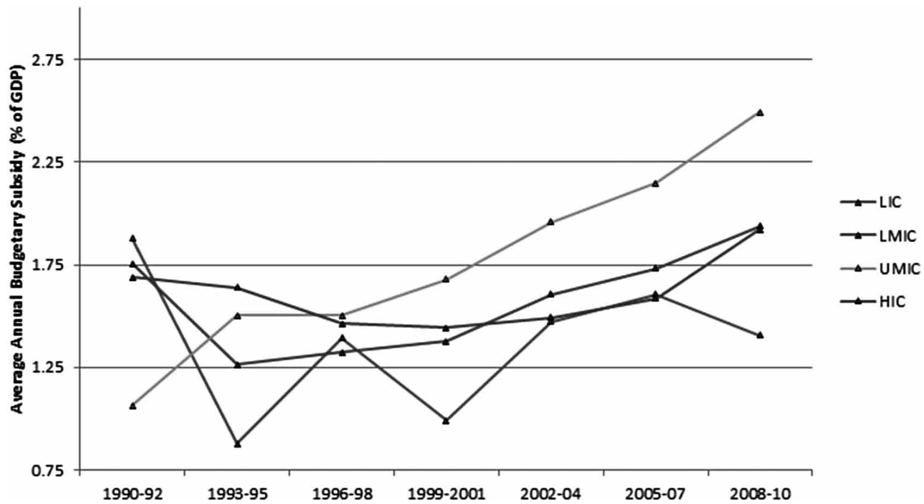
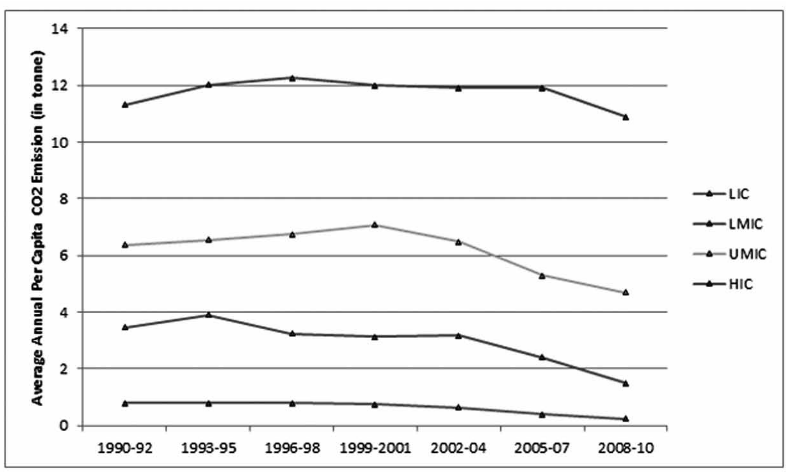


Figure 3. Average Annual Per Capita CO_2 Emission (in tonne per annum) across Development Groups
Source: Constructed by the authors from WDI data



CO_2 emission has fallen down over 2005-2009 (as compared to the 2000-2004 period), which can be explained due to the reduction commitments under Kyoto Protocol (w.e.f. 2005).

Lastly, Table 2 illustrates the data availability for the present analysis as per the IMF GFS data obtained through the online platform. The first two rows segregate the total observations as per the cash and non-cash (accrual) reporting practices. While the first three columns report data availability by the type of government, the last three columns summarize the average subsidy scenario as per the income level of the country groupings. The bottom three rows analyze the data availability scenario with respect to level of government providing subsidy, i.e., GG and others (BCG and CG) in terms of income levels of the selected countries. Certain interesting observations emerge from the table. Firstly, it is observed that most of the countries where GFS reports data for either CG or BCG, follows cash accounting method. Conversely, the countries where data for GG is available, are practicing non-cash (accrual) method of accounting. Secondly, majority of lower income (LIC and LMIC) and higher income (UMIC and HIC) countries have adopted cash and non-cash accounting method respectively. Finally, for majority of lower income (LIC and LMIC) countries GFS reports data for either CG or BCG. The wide variation in data reporting practices across the selected countries justifies the inclusion of the C_{it} and GOV_{it} dummies in the empirical model for capturing the fixed effects corresponding to accounting method and level of government.

5. EMPIRICAL RESULTS

The panel data regression analysis has been undertaken with help of the STATA software (version 13.1). To understand the working of the model for the proposed relationship in Equation (1),[7] Hausman specification test is first conducted. It is observed that the Chi-square test statistic of 313.19 (Prob.: 0.0000) is statistically significant. The Hausman test suggests the presence of an underlying fixed effect model. For detecting the presence of first order autocorrelation in the model, the Wooldridge test is then performed. The F - test statistic of 26.016 (Prob.: 0.0000) indicates the presence of first order autocorrelation. To check the existence of heteroskedasticity in the estimated model, the Breusch-Pagan / Cook-Weisberg test has been conducted. The Chi-square test statistic of 106.29 (Prob.: 0.0000) indicates the presence of heteroskedasticity. Estimated mean variance inflation factor (VIF) is 11.56, which results from the inclusion of both Log(PCGDP) and its square term in the model. For other variables, the values of VIF are within the tolerance limit of multicollinearity. Based on these diagnostic tests, the present analysis adopts Feasible General Least Square (FGLS) method with time specific fixed effects. The estimated models make correction for the presence of heteroskedasticity and first order panel specific autocorrelation [PSAR(1)] within unbalanced panel data framework.

The estimation results for various specifications of Equations (1) are summarized in columns 1-4 of Table 3, from which the following conclusions can be drawn. First and foremost, the estimation results strongly underline the adverse influence of government subsidies on Per Capita CO_2 emissions ($lpcco_2$) in the sample countries, as reflected from the positive and highly significant

Table 2. Distribution of Budgetary Subsidy Data Availability based on Level of Development, Reporting Practices and Accounting Standards: 1990-2010

		Data Reporting Practice			**Level of Development**		
		Govt. - GG	**Govt. - Others**	**Total**	**LIC & LMIC**	**UMIC & HIC**	**Total**
Accounting Standards	Cash	248	1152	1400	820	580	1400
	Non-cash	600	128	728	151	577	728
	Total	848	1280	2128	971	1157	2128
Data Reporting Practice	Govt. - GG				196	652	848
	Govt. - Others				775	505	1280
	Total				971	1157	2128

Source: Computed by authors based on IMF GFS Database

Table 3. Estimation Results on the Relationship between Budgetary Subsidy and CO_2 Emissions

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7 LIC & LMIC	Model 8 UMIC & HIC	Model 9 Difference#	Model 10
lpcco2(-1)					0.977***	0.977***				
					(0.003)	(0.003)				
lsub	0.018***	0.018***	0.021***	0.015***			0.019***	0.012**	0.005***	0.017***
	(0.004)	(0.004)	(0.004)	(0.004)			(0.005)	(0.005)	(0.001)	(0.004)
lsub(-1)			0.026***	0.019***						
			(0.004)	(0.004)						
lsub-lsub(-1)					0.004***	0.004***				
					(0.001)	(0.001)				
lpcgdp	1.154***	1.225***	1.269***	1.378***	0.110***	0.092***	1.065***	1.399***	0.275***	1.101***
	(0.081)	(0.083)	(0.075)	(0.077)	(0.013)	(0.013)	(0.201)	(0.215)	(0.058)	(0.09)
lpcgdp2	-0.042***	-0.048***	-0.051***	-0.054***	-0.006***	-0.005***	-0.037***	-0.057***	-0.006*	-0.04***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.001)	(0.001)	(0.014)	(0.011)	(0.003)	(0.005)
lagrigdpn	-0.137***	-0.17***	-0.252***	-0.158***	-0.002	0.000	-0.151***	-0.048**	0.055***	-0.155***
	(0.019)	(0.018)	(0.016)	(0.019)	(0.002)	(0.002)	(0.031)	(0.02)	(0.013)	(0.021)
lmfggdpn	0.2***			0.208***		0.004	0.295***	0.151***	0.089***	0.258***
	(0.021)			(0.021)		(0.003)	(0.022)	(0.025)	(0.019)	(0.023)
lservgdpn		-0.222***	-0.291***		-0.034***					
		(0.048)	(0.054)		(0.01)					
ltaxrev										-0.063***
										(0.023)
Lurban	1.049***	1.174***	0.939***	0.816***	-0.023***	-0.023***	0.996***	0.154**	1.054***	1.082***
	(0.048)	(0.05)	(0.042)	(0.051)	(0.005)	(0.005)	(0.048)	(0.073)	(0.202)	(0.056)
Cash	0.061***	0.079***	0.047***	0.047***	0.016***	0.018***	0.109***	0.064***	0.016***	0.146***
	(0.017)	(0.018)	(0.017)	(0.017)	(0.004)	(0.004)	(0.034)	(0.019)	(0.004)	(0.025)
Gov	-0.027*	-0.035**	-0.038**	-0.016	-0.018***	-0.02***	-0.104***	-0.032*	-0.003	-0.049***
	(0.016)	(0.016)	(0.015)	(0.015)	(0.004)	(0.005)	(0.032)	(0.017)	(0.004)	(0.019)

continued on following page

Table 3. Continued

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7 LIC & LMIC	Model 8 UMIC & HIC	Model 9 Difference#	Model 10
Constant	Omitted	Omitted	-8.284***	-9.951***	Omitted	-0.306***	-10.195***	Omitted	0.005	Omitted
			(0.311)	(0.326)		(0.059)	(0.664)		(0.009)	
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	1661	1736	1549	1491	1548	1490	824	831	1472	1330
Number of groups	131	134	131	129	131	129	90	70	129	124
Wald chi2	14855.66	12468.86	8516.87	7132.02	2625470	1772387	5420.11	15994.62	592.89	14584.1
Prob>chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: #- first difference of all continuous variables
Figure in the parenthesis shows the heteroskedasticity [*Panel(hetero)*] and Panel Specific First Order Autocorrelation [*PSAR(1)*] corrected standard error of the estimated coefficient
***, ** and * implies estimated coefficient is significant at 0.01, 0.05 and 0.10 level respectively.

coefficients. The relationship is found to be robust for all the model specifications of the budgetary subsidies term, namely *lsub and lsub(-1)*. The empirical results in elasticity terms underline that with proportional increase in the budgetary subsidy level in a country, the rate of per capita emission of CO_2 also rises significantly. Interestingly in Models 3 and 4 the coefficient of *lsub(-1)* is found to be higher vis-à-vis the corresponding coefficients for *lsub*, which demonstrates the importance of the lagged effects of budgetary subsidies on per capita CO_2 emissions in the selected sample. Secondly, among the control variables, the coefficient of $lpcco_2(-1)$ has been found to be positive and significant, implying that a country characterized by historically high level of CO_2 emissions is expected to have its current emission level influenced by the same, and vice versa. Thirdly, sign of the coefficients with respect to per capita income indicates that for one percentage point increase in *lpcgdp*, $lpcco_2$ emission generally increases by a higher proportion, barring the exception in the robustness check Models 5, 6 and 9. Fourthly, the higher order terms of income ($lpcgdp^2$) are associated with a negative sign in all the estimated models. Fifthly, the contribution of manufacturing sector in GDP is found to be positively influencing the dependent variable, while the reverse is noted in case of primary and service sectors. In other words, growth in composition of manufacturing sector in an economy results in growth of CO_2 emissions, while the rise in primary and service sectors contribute in curbing the same. The PCGDP and economic composition results provide a strong support to the existence of the EKCH phenomenon. Sixthly, the *lurb* variable is found to be positive in most of the selected model specifications, signifying the negative repercussions of urbanization. Seventhly, Model 10 indicates a negative relationship between TAXREV and $PCCO_2$, which implies that higher the tax revenue (as % of GDP) lower the per capita CO_2 emission. Finally, the cash and government dummies are found to be significant, implying the importance of the underlying accounting method and level of government data reporting practices in influencing the subsidy-climate change nexus. The result indicates that adoption of accrual accounting across the countries is desirable.

While the proposed regression models confirm the hypothesis, there is a need to verify their robustness. In Models 5 and 6, the difference in share of subsidies in GDP and its difference with the past year's value has been considered as an independent variable and the estimated coefficient is found to be positive and significant. In other words, rising difference between past and present values of subsidies lead to higher CO_2 emissions. Moreover, the estimated result of a regression model could be specific to functional form. Therefore, to check the robustness of our estimated result, we have estimated Model 9 where first differences of all continuous variables are taken. Neither the sign nor the significance level of key policy variables changes in this model. In addition, by splicing the sample countries into two groups, namely LIC & LMIC and UMIC & HIC as per the relevant income definitions, the robustness of the proposed relationship has been checked through Models 7 and 8. The coefficient of *lsub* is found to be positive in both models, but the coefficient for the lower income countries are found to be larger vis-à-vis the same for their higher income counterparts. The observation can be explained by the fact that provision of subsidies in the lower income countries may potentially lead to greater CO_2 emissions given the possibility of natural resource base erosion.

A couple of interesting conclusions on the influence of subsidies on CO_2 emissions can be drawn by summarizing the regression results. First, the coefficient of *lsub* for the lower and higher income countries are 0.019 and 0.012 respectively, signifying greater emission growth in the former group in response to percentage increase in budgetary devolutions. In addition, the coefficient of *lpcgdp* for the lower and higher income countries are 1.065 and 1.399 respectively. The observation indicates that per capita income growth in developed countries potentially leads to higher CO_2 emissions, vis-à-vis the corresponding figures for their lower income counterparts. The difference in CO_2 emissions pattern across the two income groups can be explained by existing higher level of output in the richer economies which is in line with the predictions of the *scale effect*, as discussed earlier. However, growth in devolution of subsidies may harm the sustainability of the lower income countries more severely.

Secondly, the coefficients of *lmfggdp* for the lower and higher income countries are found to be 0.295 and 0.151 respectively. In other words, the growth in manufacturing sector output in lower income countries potentially leads to higher CO_2 emissions growth, vis-à-vis the corresponding figures for their higher income counterparts. The result underlines the current scenario in several UMIC and HIC countries, who are experiencing relatively steeper decline in per capita CO_2 emissions in recent period (Figure 3). It is evident that the rise in manufacturing sector output, if not associated with adequate compliance mechanism, may add to sustainability challenges. The positive and negative signs of the coefficient for *lmfggdp* and *lagrigdp* respectively also indicate the presence of a strong *composition effect* in both set of economies.

Finally, the negative coefficient of $lpcgdp^2$ both in lower as well as higher income countries indicates the decline in the per capita CO_2 emissions with further rise in income. The estimated results signify the presence of an EKCH type relationship with reference to emission of per capita CO_2. Nevertheless, the coefficient for lower income countries (-0.037) is found to be smaller than the corresponding figure for the higher income countries (-0.057), indicating a sharper fall in the latter set of economies. The notion of development difference receives further support from the difference in the magnitude of the coefficient for the *lurb* variable for the two set of countries. While the coefficient is found to be 0.154 for the higher income countries, the same for the lower income countries is 0.996. In other words, the growth in urban population and consequent deepening of economic activities leads to far greater per capita CO_2 emissions growth in lower income countries. The result underlines the existence of arising demand for cleaner environment and better environmental governance in higher income economies, which is in line with the predictions of *technique effect* and EKCH.

6. CONCLUSION

Supporting domestic players through subsidies for fulfilling both short term and long term objectives is a time-tested policy instrument across countries. The sustainability repercussions of such subsidies are the focus of the present empirical analysis. The broad conclusions emerging from the findings are noted in the following.

First, the positive and significant relationship between importance of subsidy devolution in GDP and per capita CO_2 emission pattern of the sample countries is in line with the theoretical predictions, as the overall budgetary support or the same to certain specific economic activities may lead to over-use of environmentally harmful inputs (e.g. fossil fuels) and cause over-production, resulting in climate change concerns. The relationship holds good for the entire sample of countries as well as is the spliced sample, which analyze the effect of subsidies separately for both low-income and high-income countries. The results underline the sustainability concerns emanating from devolution of such subsides in all economies cutting across income groups and irrespective of the tier of government undertaking such measures in no uncertain terms.

Secondly, the empirical results relating to income level and sectoral composition of GDP are in line with the EKCH predictions that as the importance of the manufacturing sector in the economy gradually increases, it worsens the scenario on emissions front. On the other hand, prominence of primary and service sectors in GDP is associated with decline in CO_2 emissions. Interestingly, this influence is found to be stronger in the lower income countries due to the base effect, as the subsidies may facilitate movement towards the manufacturing-led pollution peak described under the EKCH. The result can also be explained by the fact that *technique effect* is weaker for the lower-income economies, while the *scale* and *composition effects* get escalated there through the devolution of subsidies.

It is clear from the analysis that the climate change concerns seem imminent for both high-income (UMIC & HIC) and low-income (LIC & LMIC) countries. While for high-income group, the presence of a relatively stronger *technique effect* may partly compensate for the adverse effects of budgetary devolutions, adverse *scale* and *composition effects* are clearly witnessed for these economies as well from the empirical estimation results. Figure 1 clearly indicates that the budgetary subsidies expressed as percentage of GDP as well as the per capita CO_2 emissions are relatively higher for richer countries as compared to their lower income counterparts. However, low-income countries also need to urgently pay heed to the adverse influence of budgetary subsidies on per capita CO_2 emissions, as the presence of the *scale* and *composition effects* are clearly not contained through a weaker *technique effect* in these economies.

The observation of the empirical analysis strongly underlines the need for an early conclusion of the negotiations under UNFCCC forums to secure GHGs reduction commitments from countries across all development spectrum. One practical challenge however is that while awareness on the adverse effects of existing subsidies has increased over the years, removing or curtailing their effects by securing binding reduction commitments in Member countries through multilateral negotiations is difficult owing to a multitude of political economic considerations based on domestic compulsions. The multilateral negotiations on subsidies are being conducted on two fronts. On one hand, the ongoing negotiations at the multilateral trade forum, i.e., WTO, are geared towards containing the ill-effect of subsidies which facilitate over-production and incentivize input overuse (e.g., output price support, fossil fuel subsidy) beyond the *actionable* level and limit future abuse through similarly harmful support measures. On the other hand, the major objectives of various multilateral environment-related forums, e.g., United Nations Conference on Sustainable Development (UNCSD), United Nations Framework Convention on Climate Change (UNFCCC) etc., include reduction of the GHGs emissions and protection of biodiversity, with particular focus on reduction of harmful subsidies like fuel subsidies. The modest achievements at both the negotiations conducted under WTO and the UN forums in securing meaningful subsidy reforms across countries however remains an area of major concern and underline the urgent need to conclude the negotiations in no uncertain terms.

The developments at the UNFCCC negotiations at Lima in December 2014 are heartening in this background, where the member countries have been able to make some headway. As per the *Lima Accord*, both the high-income and low-income countries have agreed to control the emissions of GHGs through reduction in burning of fossil fuels. The agreement aims to reach, "an ambitious agreement in 2015 that reflects the principle of common but differentiated responsibilities and respective capabilities, in light of different national circumstances" (UNFCCC, 2014). The countries are expected to communicate the policies and strategies to be undertaken within their territories by the first quarter of 2015. The discussions at Lima also leave room for special and differential treatment by noting that, "least developed countries and small island developing States may communicate information on strategies, plans and actions for low greenhouse gas emission development reflecting their special circumstances" (UNFCCC, 2014). One significant drawback however is that the agreement does not call for emissions reduction in the countries by binding to a pre-determined commitment level. Hence, the potential for actual reduction in harmful subsidies across countries in subsequent negotiations remain uncertain.

A more serious concern is that, in line with the aforesaid discussion, the movement towards reduction of GHGs emissions through the UNFCCC forums may actually lead to a trade war in the WTO forums. Already several complaints has been lodged at the WTO Dispute Settlement Body alleging violations in the 'green subsidy' programmes i.e., subsidies offered to facilitate shift to alternate and renewable energies in Member countries. Therefore, in the absence of a strict guideline on disciplining devolution of subsidies, countries may attempt to achieve reduction in GHGs emissions within their territories by merely channeling the fiscal devolutions from fossil fuels and allied sectors to the renewable energy sources, fueling areas of discords in future. The upcoming UNFCCC negotiations need to adequately focus on this aspect.

The current empirical analysis suffers from two limitations owing to the availability of subsidies data at present. First, a consistent cross-country long time series data on indirect / implicit subsidies through revenue foregone (i.e., income foregone in terms of tax rebate / exemptions etc.), which can affect CO_2 emissions significantly, is presently not available. The present analysis is therefore based entirely on direct subsidies, which involves budgetary devolutions (i.e. transfer of financial resources). Second, the underreporting of subsidies data is an acknowledged problem in trade literature (WTO, 2006). In future, development of a comprehensive database by multilateral bodies capturing all forms of subsidies provided by countries would facilitate a more insightful policy analysis on this front.

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ENDNOTES

1 A comprehensive review of definitions of subsidies and their measurement issues has been undertaken in Jones and Steenblik (2010).

2 Fisheries sector is a case in point, which is a major recipient of implicit subsidies (Chakraborty and Kumar, 2010).

3 Collection of taxes on environmentally sensitive activities ideally should have been incorporated in the model. However, long time series data on taxes on pollution is not available for most of the LDCs and developing countries, as adoption of fiscal instruments in that sphere is only a recent concept for these economies (Mori et al., 2014). Instead, overall tax collection (as percentage of GDP) has been considered in the model here.

4 Available online at: http://elibrary-data.imf.org/QueryBuilder.aspx?key=19784658&s=322 (last accessed on 11 July 2014)

5 Available online at http://elibrary-data.imf.org/QueryBuilder.aspx?s=322&key=1445284 (last accessed on 25 April 2014).

6 This is in line with World Bank classification of countries based on per capita Gross National Income (GNI) (Source: http://data.worldbank.org/about/country-classifications - last accessed on 24 April 2014).

7 In equation 1, We drop *lsubi(t-1)* from the list of regressors to carry out diagnostic tests for selection of appropriate specification of the regression model.

Chapter 29
Social Innovation:
A Theoretical Approach in Intertwining Climate Change with Social Innovation

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ABSTRACT

In this paper an attempt has been made to link the understanding relating to innovation in organisations with that of societal innovation at large which was later on extended to summarise the literature of social innovation and climate change. The organisation forms part of (and exists in) the social system. From the view point of organisational studies the social system may be seen as consisting of two levels while the immediate vicinity of the organisation encompasses the various organisational stakeholders and correlates the second level pertains to society in general. According to Savvides (1979), the second level encompasses the first which in turn encompasses the organisation. In this paper a comprehensive review has been presented for a better understanding of social innovation its correlation with climate change through the concepts used to understand organisational innovation.

INTRODUCTION

Social Change and Innovation

Changes in the structure and functioning of either level, but especially in level one constitute social change. (Rogers 1969) defined social change as "the process by which alteration occurs in the structure and function of a social system". Social changes may create performance gaps as in, International Sector, Education Sector, Competitors, Suppliers Customers Unions, Technology Govt, Agencies, which can collectively affect the Organisation Society in general thereby orchestrating changes in the immediate external environment of the Organisation (Savvides, 1979).

Performance gaps are discrepancies between what the society could do by virtue of a goal-related opportunity in its environment and what it actually does in terms of exploiting that opportunity. The performance gap may be characterised by resources not getting fully exploited brought about by changes among the patterns of consumption, or by loss of previous opportunities because of new competition, or by any other change in the environment. A performance gap may also come

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about by changes within the society, such as when a key societal player leaves the societal mileu.

Innovation in society is mostly administrative in nature.This essay examines first how effective innovation is basically a effective synergy of both organisation and society in general involving stakeholders from both organisations and society at large and later addresses the complex aspect of climate change for a better understanding of the role of various stakeholders as per Savvides(1979). A thorough review of the literature is undertaken and an evaluation of the state of the art is made, the issue then becomes, if it is not possible or practical to change the functioning of the organisation to accommodate change as situations warrant it as per the alternatives opened to society at large and how can it be provided that the conditions for facilitating innovation in the society are adequately catered for (Savvides, 1979).It is from this perspective that the author has tried to understand the various endeavours relating to social innovation in different areas namely climate change, agriculture and inequality.

In every instance the author has tried to substantiate the importance of different stakeholders as per Savvides (1979) in implementing optimal grass root social innovation.

INNOVATION AND THE INNOVATIVE PROCESS

What is Innovation?

The definition of innovation is not of great practical importance. What is more important is the changes that are needed in an organisation to close or minimise its performance gap. It is only because, as it happens, the vast majority of organisational changes needed in such situations involve novel solutions and new approaches that the subject of innovation becomes important.(Savvides,1979)

There are basically three ways that innovation has been defined. First, there is the school of thought that, strictly speaking, avoids defining innovation objectively by leaving it on the subjective judgement or perception of the adopting unit to decide what is new (e.g. Rogers and Shoe-maker 1974). Zaltman, Duncan, Holbek (1973), Bennet (1969).Second, there is the school of thought that does not concern itself with that innovation means and concentrates on specifying different aspects and stages of the innovative process. An example of these is the one offered by V.A. Thompson (1969) which states “innovation is the generation, acceptance and implementation of new ideas, processes and products or services”. Similar definitions are those by Steiner (1965) and National Academic Sciences (1969). Thirdly, there is the school of thought that attempts to emphasise objectively measurable qualitative differences. An example is the one by Barnett (1953)”… any thought, behaviour or thing that is new because it is qualitatively different from existing forms.”

The emphasis on different stages of the innovation process in defining innovation shows that there is more disagreement among academics as to where the innovation begins and ends rather than on the substance or essence of the word itself. Perhaps the most practical definition of innovation for our purposes is the one put forward by Zaltman, Duncan and Holbek (1973) which states that innovation is “any idea, practice, or material artefact perceived to be new by the relevant unit of adoption”.Thus we can postulate that understanding social innovation becomes all the more easier or logical by taking the second or third view relating to innovation as Social innovation in the context of climate change often entails the fact that social innovation processes often becomes very difficult to segregate as it involves complex intertwining between the different stakeholders thereby making the contribution of individual contributors often blurred.

SOCIAL INNOVATION AND CLIMATE CHANGE

Climate change affects every part of the right from the organisation to the different stakeholders. Thus (Savvides, 1979) approach in understanding societal and organisational interaction all the more important.Savvides (1979) depicted the different external peripheries surrounding a organisation thereby making the process of segregation and intertwining social and organisational innovation much easier. In this chapter we will discuss social initiatives relating to climate change both within organisation as well as within societies. The current strategies for combating climate change reflect the technological, commercial and industrial dominance of our market led society. Meanwhile, people's behaviour is seen as separate from these predominantly technological solutions, and is considered difficult to influence and change. As an alternative, we here draw attention to bottom-up, social innovation as an overlooked, but potentially significant contribution to climate change mitigation.

New low-carbon social practices – sometimes involving technology – are emerging in localised niches like communities and work places. The distance of these origins from the established power structure make such innovation less visible and less supported, and this is exacerbated by their often non-commoditised form, which fits less well with mainstream, market-oriented ways of diffusing novelty across society. All this makes them difficult for policy makers to address, with widespread adoption of policy measures to drive forward application of social innovation prone to various barriers.Social science has a role to support low carbon, bottom-up, social innovation, as well as to uncover its potential.(Bergman et al,2010)

In this chapter the author has tried to emphasise bottom up social innovation relating to climate change as in most innovation discourse, the focus is normally on mainstream, established actors in industry, academia and government. But bottom-up, social innovation has played an important part in shaping modern society, with civil society rather than the organised corporate or government entities often providing the impetus for social change. The industrialisation and urbanisation of the nineteenth century were accompanied by extraordinary social innovation including new models of childcare, community development and social care in Britain, all originating in civil society (Mulgan 2006). More recently, environmental NGOs have been instrumental in pioneering social practices, and their proposed policies have since become government policies in many countries (Henderson 1996) and behavioural change has been identified as being a necessary and key element of meeting environmental goals (DEFRA 2008).And as for the future: 'There is every reason to believe that the pace of social innovation will, if anything, accelerate in the coming century' (Mulgan 2006). Government policy in support of innovation is strongly focussed on technical, commercial activities, giving little attention and resources to social, not-for-profit innovation.In the climate change context,(Bergman et al,2008) recognises that a shift in the innovation focus is needed, with not only technological change, but societal change including cultural and behavioural changes as essential elements. This conjecture finds a parity with Savvides (1979).The UK government recognises that it is not just technical feasibility or even the economics of solutions, but also 'non-economic barriers' and 'non-technical barriers' that need to be overcome. This shift has led to more interest in communities and local places as sources of innovation (Steward et al. 2009). Finally, social innovation could help spread technological innovations or maximise their benefits as new norms or institutions increased the demand for various 'greener' technologies and technical solutions. One significant problem with social, bottom-up, low-carbon innovation as stated by Bergman et al (2008) is the difficulty in assessing outcomes: it is hard to quantify the effects of a phenomenon that is not standardised or traded and which might include potentially nebulous outcomes. This can be difficult as regards carbon reduction and even more complex in terms of outcomes like social inclusion, social capital, etc. It can also be argued that this is one of the reasons why more research is needed about this class of innovation. For this reason, we limit this paper to *intentional* low-carbon innovation, in line with the definitions above emphasising the intention to achieve common goals and meet social needs. In the rest of the paper we will give a brief review of social innovation in the literature, giving appropriate examples of such innovation. We then look at the dynamics and barriers to social innovation, using some social science theories, and sum up with some conclusions.

Empirical Work to Date on Local, Bottom Up, Social Innovation

The Empirical Literature

So what characterises the empirical literature to date on bottom-up, low-carbon, social innovation? Bergman et al(2012) found a rather disjointed body of work, with coverage of a series of specific empirical problems that are not commonly conceived of as areas of innovation. Examples of this include the literature on social or sustainability entrepreneurship which emphasises the role of small (or single) businesses in innovating for a sustainable society (Horst 2008, Parrish 2008). There are a series of contributions on grassroots initiatives such as Local Exchange Trading Schemes (LETS),and other action by the voluntary and community sector (Seyfang 2006b, Middlemiss and Parrish forthcoming). Other work looks at workplace innovation, including the role of workplace champions in transforming public and private sector organisations (e.g., Markusson, 2009). Some of these contributions have begun to draw on transitions theory as a common theoretical approach (Seyfang and Smith 2007, Parrish and Foxon 2009).

Alongside this academic literature we can see a series of bottom-up, low-carbon, social innovations happening in society at large which are attempting to address climate change issues. The recent burgeoning of Transition Town initiatives is the most visible example in the UK of how an innovative social form related to environmental issues can evolve (Transition Towns Network 2008). Transition Towns have been replicated around the UK and overseas. Bergman et al took a rather loose definition of bottom-up innovation, to include independent action by innovative actors (whether based in large or small organisations), a series of other examples come to mind. For instance, local councils are finding new ways to fund and implement radical programmes, such as Kirklees Council's insulation of every house under its jurisdiction (Kirklees Council 2009). Social innovations sometime accompany technical innovation. This is exemplified by Ray Anderson's reform of his carpet manufacturing company Interface, the radical change he stimulated to reduce his company's impact on the environment required both technical and social innovation (Anderson 2006).

Case Studies of Low Carbon, Bottom-Up, Social Innovation

A series of examples of innovations from the literature follows, starting with social innovations that involve new institutions and practices, followed by innovations that also impact on technology.

Grassroots Action on Climate Change

The emergence of Transition Towns forms part of an upsurge in interest in grassroots innovation in practitioner, academic and policy circles (Defra 2005, Seyfang 2006a, Middlemiss and Parrish forthcoming). Note, this kind of activity is rarely labelled 'innovation' but, given its focus on creating new institutions through which to address participant and community practices, it is clearly an innovative movement. Grassroots innovations involve a group of socially motivated volunteers adapting tools like the Transition Towns Handbook, the Eco Teams programme (see Global Action Plan 2010), or LETS, to their specific local needs, or inventing new ways of engaging with each other and their and their local communities. In doing so they create variants of an innovative type of organisation: a voluntary association of citizens who act together in creative ways on climate change issues. Such grassroots innovations for climate change act on a belief by stakeholders that locally instigated initiatives have more power to effect change than do top-down initiatives (Transition Towns Network 2008).

Bollington Carbon Revolution (BCR) is an example of socially-driven innovation at the grassroots level (Middlemiss and Parrish forthcoming). This community group is attempting to reduce the Cheshire town of Bollington's carbon footprint by running a series of activities around climate change. The name 'revolution' is a positive take on climate change, as the group see the climate problem as an opportunity much like the industrial revolution, during which Bollington prospered.Like many of these initiatives, BCR has adopted some of the resources, tools and ideas for social change available in the public domain (including showing films such as The Inconvenient Truth,using the EcoTeams programme, taking up community gardening, and exploiting the tradition of community action that exists in the town). Equally BCR has drawn on its own resources in innovative ways, for instance persuading the local council to set up a grant to subsidise insulation for local householders. Many of the members of the group use their professional skills within the community context to apply for funding, and to organise the group. These volunteers tend to be involved in their community for the first time, and as such have to invent new ways of working together in this informal context. This includes finding means of coping with the transient nature of volunteers. (c.f Bergman et al, 2010)

Combating Climate Change through Social Adaptation

While there is a recognised need to adapt to changing climatic conditions through interventions or consequent incremental innovation nevertheless climate change literature has thrown up the need to an even newer discourse of climatic adaptation in the form of adaptation.

What is Adaptation?

Individual and societal adaptation to climate is nothing new, neither as an empirical reality nor as a theoretical construct. The resource irregularities offered by different climates and the precariousness which emerges from the vicissitudes of climate have both acted as significant stimuli throughout human history for social and technological innovation. Irrigation, insurance and weather forecasting are just three of the many human institutions which have been prompted and shaped by the interactions between our physical and imaginative encounters with climate. They are examples of how we have adapted our social practices in the face of variable climates. In a new, deliberative and self-conscious way, however, adaptation to climate change has now become part of the contemporary discourse about the politics and economics of global climate change. It has been enshrined in the policy debate through its appearance in Article 2 of the United Nations Framework Convention on Climate Change UNFCCC), where the ultimate objective of the Convention concedes that adaptation to climate change in relation to food production, ecosystem health and economic development can and will occur. Although much of the earlier international climate policy debate in the 1990s and early 2000s was pre-occupied with mitigation, the past decade has seen a growing attention given to adaptation—both its practice and its politics (e.g. Parry et al. 1998; Pielke et al. 2007).

There is an emerging discourse of limits to such adaptation. Limits are traditionally analysed as a set of immutable thresholds in biological, economic or technological parameters. (Adger et al,2008) contends that limits to adaptation are endogenous to society and hence contingent on ethics, knowledge, attitudes to risk and culture,insights from history, sociology and psychology of risk, economics and political science to develop four propositions concerning limits to adaptation. First, any limits to adaptation depend on the ultimate goals of adaptation underpinned by diverse values. Second, adaptation need not be limited by uncertainty around future foresight of risk. Third, social and individual factors limit adaptation action. Fourth, systematic undervaluation of loss of places and culture disguises real, experienced but subjective limits to adaptation. (Adger et al, 2008)

Thus (Adger et al, 2008) avers that the implicit assumption that successful adaptation to climate change will be bound by limiting factors beyond which adaptation will not be possible The propositions in effect challenge this view and maintain that societal adaptation is not necessarily limited by exogenous forces outside its control. More often, adaptation to climate change is limited by the values, perceptions, processes and power structures within society. What may be a limit in one society may not be in another, depending on the ethical standpoint, the emphasis placed on scientific projections, the risk perceptions of the society, and the extent to which places and cultures are valued.

The Nature of Adaptation Limits and Four Propositions

Within the climate change literature, adaptation is generally 'adjustment in natural or human systems in response to actual or expected climate stimuli or their effects,which moderates harm or exploits beneficial opportunities' (McCarthy et al. 2001,p. 982). In essence, adaptation describes adjustments made to changed environmental circumstances that take place naturally within biological systems and with some deliberation or intent in social systems (Gallopin 2006; Nelson et al. 2007).

According to (Adger et al,2008) the discourse around limits to adaptation is frequently constructed around three dimensions—ecological and physical limits, economic limits, and technological limits.These dimensions offer various analytical capabilities for investigating adaptation to climate change and allowing adaptation to be present in various forms of policy assessment.

Attention to ecological or physical limits to adaptation offers the prospect of investigating of such limits through physical modelling of, for example, agriculture and biodiversity under changing climates. Consideration of economic limits to adaptation lends itself to investigation through the use of cost-effectiveness analysis or cost–benefit analysis,(Adger et al,2008). Approaching limits to adaptation through an appreciation of technology suggests value in various types of technology mapping and innovation analysis, for example as applied to coastal defence or building design.

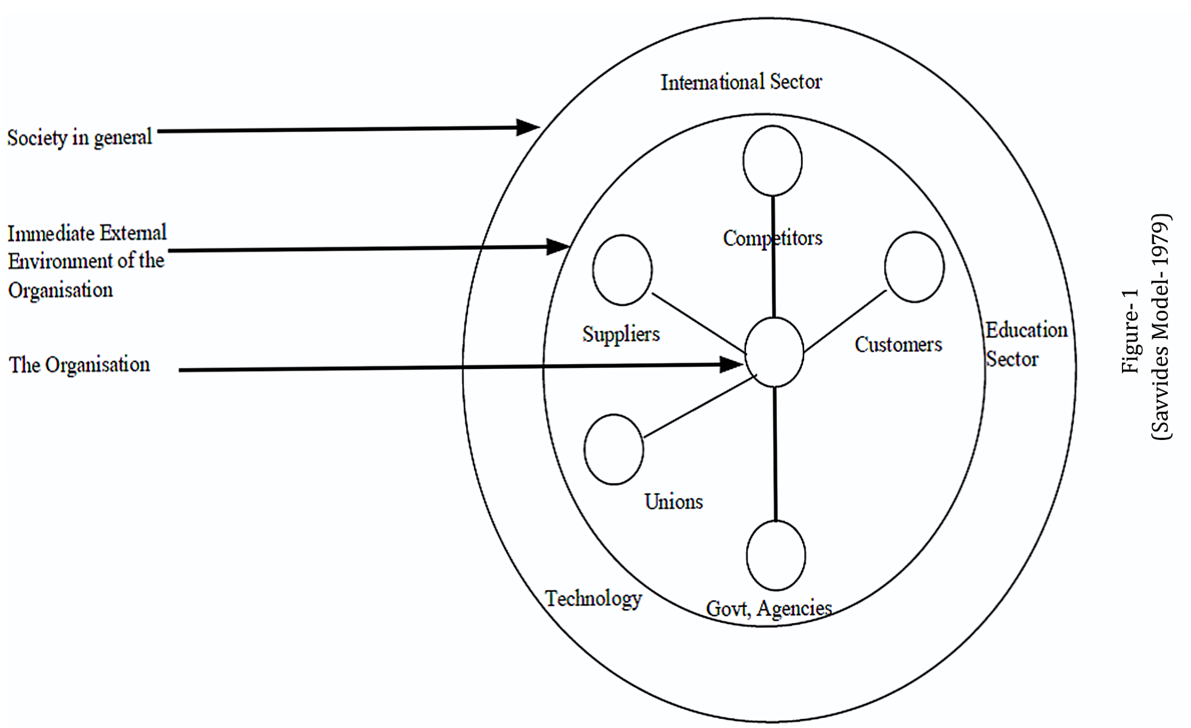
These ways of conceiving limits to adaptation are attractive because they offer analytical functionality, a functionality which sits easily alongside other key dimensions of climate change analysis: modelling changes in the Earth system and energy economic modelling of mitigation policy. Indeed, the framing of Article 2 of the UNFCCC points in this direction, suggesting that there are independent, objective measures and thresholds of danger (Dessai et al. 2004; Oppenheimer 2005). On the other hand, these conceptions of adaptation limits imply that such limits can be defined predominantly in either exogenous or analytical terms. The conceptions give great weight to limits imposed from 'outside society' or limits where the risk can be quantified. (Adger et al, 2008)

In this technological discourse, adaptation limits become synonymous with ecological thresholds, where a threshold refers to a state in sensitive ecological or physical systems beyond which change becomes irreversible. Such thresholds are beginning to be identified in ecological literature and refer to habitat ranges, ecosystem functions and threats of extinction of particular species (Parmesan and Yohe 2003; O'Neill and Oppenheimer 2002; Fischlin and Midgeley 2007). In addition, adaptation limits may also emerge from analyses of the economic costs of adaptation (e.g. Agrawala and Fankhauser 2008) or from the prospects for technological innovation for adaptation. These limits to adaptation are absolute and objective.

In contrast to the above caricature of adaptation limits as exogenously or analytically defined, we approach the question of limits to adaptation differently. Hence (Adger et al,2008) conjectured that thinking about the ways in which societies are organised, the values that they hold, the knowledge that they construct and the relationships that exist between individuals, institutions and the state all form a chain of stake holders as per the model of Savvides(Figure 1). These organisational arrangements and social values are likely to vary widely within and between societies and are likely to change significantly over time (Inglehart 1997; O'Brien 2009). Values in this context refer to the personal or societal judgement of what is valuable and important in life. Values translate into action because they frame how societies develop rules and institutions to govern risk, and to manage social change and the allocation of scarce resources (Ostrom 2005). Indeed values, in some philosophical positions, are manifest in the processes and institutions that regulate behaviour rather than in the outcomes of resource allocations *per se* (Norton 2003).

In Adger's (2008) approach to thinking about adaptation, limits are endogenous and emerge from 'inside' society. In this reading, what is or is not a limit to adaptation becomes a contingent question. It all depends on goals, values, risk and social choice. Thus according to (Adger et al,

Figure 1. Savvides model, 1979



2008) limits to adaptation are mutable, subjective and socially constructed. How limits to adaptation become constructed, rather than how they are discovered, becomes the operative question. (Adger et al, 2008)

This alternative conception of limits to adaptation suggests to us four metadomains whose roles need to be explored in this social construction of adaptation limits: ethics (how and what we value), knowledge (how and what we know), risk (how and what we perceive) and culture (how and why we live). Each of these four domains interacts with the realities and constraints introduced by the physical world—including the weather and climate we experience, the consequences of changes to the climate system and the material impacts these changes cause. But our approach to the limits of adaptation places the locus for their construction inside society rather than outside it. (Adger et al, 2008)

Thus four propositions about limits to adaptation each of which draws upon one of these four domains which were conceptualised by (Adger et al, 2008)which in turn are based upon ethics, knowledge, risk and culture—which can be correlated with Savvides (1979) model involving complex synergy between the different societal stakeholders.

Theory of Induced Innovation as Applied to the Environment

Nord Haus (2002) presents a model of induced innovation that can describe the impact of changes in prices or regulations on the innovations in different sectors. At any given time, society has a stock of existing general and sector-specific basic knowledge and applied and engineering knowledge. By investing in improvements in the stock of knowledge, society can improve the productivity of its resources. Inventive activity in market economies is fundamentally a private sector activity, so the decisions about the allocation of inventive activity depend on private sector incentives. The allocation to particular sectors will depend on the relative sizes of different sectors, the degree of appropriability, and the underlying "innovation-possibility frontier" (the production function for producing new knowledge). These functions are derived from or calibrated to empirical studies that analyze the inventive process. The calibrated innovation production function is then embedded into a model of the economics of global warming to determine the impact of innovation on the important variables, such as the time path of greenhouse-gas emissions and concentrations, and climate change, along with the policy variables.

The analytical background for the model was developed by NordHaus (2002) which is again beyond the scope of this endeavour. The discussion as laid out by Nordhaus (2002) lays out the model of technological change to be used in the simulations that follow. In describing the analytical and modelling framework, Nordhaus discussed five issues: (1) the underlying model of technology, (2) the firm's decision framework, (3) the divergence between social and private return, (4) the functional specification of the induced innovation function, and (5) the welfare implications of induced innovation.

Nordhaus (2002) work is very important as in this chapter we have tried to understand social innovation endeavours relating to climate change by both firm as well as non-firm entities. When innovation is without much governmental/corporate support it is termed as bottom up social innovation. But most of the products accruing to an increase in climate change is basically from corporate and profitable governmental organisations. It is at this aspect of empirical understanding of the need for green innovation from the perspective of corporates that the work of Nordhaus (2002) deserves special mention.

Workplaces as Sites of Social Innovation

Workplaces are important settings for innovative decisions including low carbon social innovation. In addition to top-down company strategies, employee initiatives have a demonstrated history in driving innovation in the private sector (Bergman et al 2010). De Jong (2006) suggests that the role of such actors has been under-investigated even with regard to economic activity, let alone social innovation. Work place initiatives are often led by individuals, as 'environmental champions', but the emergence of successful champions is also a matter of opportunity, offered to the individual by his or her social context (Bergman et al, 2010). An organisational environmental strategy and – not least – strong regulatory pressure can open up opportunities for individuals to successfully promote environmental action and environmental championing can be a matter of expressing personal concern and reconciling private life interests with the work situation, but it may also be done to further one's career for more pragmatic or individualistic reasons (Bergman et al,2010). In industry, the context in terms of especially regulatory pressure is more important than (at least moderate) differences in general norms in national culture and levels of public awareness expressed through individual initiatives in the workplace. The strength of contextual shaping may be different in public sector or civil society organisations, (Bergman et al 2010).

AGRICULTURE MECHANISATION AND NEED FOR SOCIAL INNOVATION

Social Innovation and Agriculture

In the case of Agriculture Production the last 50 years witnessed a remarkable spread of smaller-scale rural mechanization in some regions of South Asia mostly characterized by the spread of single cylinder diesel engines. These engines have been used for multiple purposes, such as providing power for shallow tube well pumps, river boats, 2-wheel tractors, road and track transport vehicles, harvesters, threshers, grain mills, timber mills, and processing equipment. Diverse local market institutions for the buying and selling of water, tillage, transport and many other services have been associated with the spread of smaller-scale rural equipment. Alongside these smaller scaled patterns if rural mechanization there have been significant increases in the intensity of agricultural production, and in broader based rural development. Despite this evidence, international and local policy debates do not reflect the significance of these patterns of rural mechanization for agricultural and rural development. This sub chapter begins with a discussion of three main generalizations arising from the spread of smaller-scaled technology. Policy issues are then started by identifying four themes that explain why this smaller-scaled mechanization transformation remained below the horizon in policy debates outside the regions where these changes have been taking place.

In the past few years, patterns of rural mechanization have taken on a new significance with concerns over, among other issues, future global food supplies, food wastage and debates around "land grabs", food security, rural employment, energy generation and use, and water scarcity. These concerns encompass the broader questions of whether, and under what circumstances, rural development should be seen as an important development goal.

When discussions of future global food supplies are presented in the press, they are often accompanied by pictures of large scale equipment such as powerful four-wheel tractors (4WTs), large combine harvesters (like aircraft in formation) and large scale irrigation schemes. In land grab situations, if the land acquisitions are for agricultural production, there is generally a large scale, highly mechanized agricultural production, processing and marketing processes involved. Articles and pictures of rural economies where smaller-scale mechanization plays a central part to increasing agricultural and other rural economic activities are seldom seen. Despite the media's presentation, over the last 60 years smaller-scale equipment has been spreading throughout much of East and South Asia. Many "green revolutions" have come about not as a result of the spread of larger 4WT and large combine harvesters, but as the result of the spread of smaller scale equipment such as two-wheel tractors (2WT), shallow tubewells, smaller-scale low lift pumps, small engines on boats and artisanally made 3 and 4-wheel "rural" transport vehicles. Whereas much attention has been given to the role of high yielding crop varieties in past green revolutions, little has been paid to the equally important role of engineering equipment for timely land preparation and sowing, careful water management, harvesting, threshing, and the local processing, transporting, and marketing of agricultural and other rural products, all of which leads to productivity gains and increases in cropping intensification It is at this aspect social innovation for changing the mindsets at the rural level and also to change to optimally mechanised agriculture so that food production can be minimised. It is required as while use of machinery in farming does not directly lead to increase in yields it does allow for more on time planting, plant protection and harvesting which do increase yields and reduce losses.

Most past Asian green revolutions relied on cheap energy policies for the agricultural sector through subsidized fossil fuels, electricity, and urea. In addition, agricultural machinery was often subsidized with capital grants and low interest loans. The future for many South Asian countries will depend on a more careful investigation of the short and long term outcomes of alternative patterns of rural mechanization. In the 1970s and 1980s, there were major "choice of technique" policy debates concerning rural mechanization, but by the 1990s the debates had nearly ceased. Since the 1970s many different patterns of rural mechanization have taken place in different parts of the world. In the past, the choices of techniques have been limited to commercially available, western manufactured large scale machinery. Paradoxically, after the decline of the debates choice of techniques greatly expanded in the origins and numbers of manufacturers and expanded in scale to commercial small scale machinery. In this discourse the author has focussed on the spread of these commercial smaller-scale agro-machinery and rural equipment such as 2WTs, low lift pumps, pumpsets for shallow tubewells, hullers, and mills and even river boats and rural manufactured three-wheel rickshaws, and four-wheel country trucks, mostly powered by the single cylinder pumped by diesel and petrol engines3 (up to 25 horsepower).The term rural mechanization rather than agricultural mechanization is used because it is only rarely that one can separate agricultural mechanization from other rural economic activities. Paradoxically, the term "tractor" conjures up in many people's minds a tractor that is used for agricultural uses. However, in many parts of Asia, tractors and especially 2 and 4WTs tractors are often used as much for transportation purposes as for agricultural purposes. Although technical engineering details are important, so too is historical, economic and social research information and it is this overarching policy analysis that should be our focus. Second, a comprehensive review is beyond the resources we have at our disposal. Finally country, local and regional analysis involving local expertise is probably the most critical policy issue at the moment.

India

Since the 1980s the Indian government has made significant investment in smaller-scale equipment through agricultural research and extension policies. The All India Coordinated Research Project on Farm Implements and Machinery and the various departments of agricultural engineering in the many agricultural universities in India have long term projects for the research, development and promotion of small scale agricultural machinery. Other Central and State funded programs provided large and long term subsidies for 2WTs and small machinery. However, if one looks at access to powered machinery for tillage, harvest and threshing, India looks very different from its neighbours. In Bangladesh and Sri Lanka over 80% of tillage operations are mechanized- mainly by 2WTs, whereas in India mechanized tillage and crop establishment makes up 45% (Agriculture Today, 2012, Kulkarni 2009, Pandey 2009).The slow spread of smaller-scale equipment in India is a paradox. Bangladesh, with 49% of the total has an estimated 500,000 2WTs, whereas the whole of India has 350,000 or 39% of the total. Ten years ago there was an even wider disparity with 350,000 in Bangladesh and approximately 120,000 in India. From the 1970s, the government supported Japanese-Indian 2WT joint ventures of which only two survive. From the 1980s to 2000, VST Bangalore from Mitsubishi and Kamco Kerala from Kubota, had nearly the whole market to themselves, and selling relatively higher quality but also much higher priced 2WTs. Recent industry reports state that 2WTs sales started picking up in 2005, and by 2010 the industry had a growth rate around 20% per annum. Recent sales are reported upwards from 45,000 to 55,000 per year. In contrast, in 2001, sales were well below 20,000 (Kulkarni 2005). In the 1990s, Chinese 2WTs began making inroads and today, according to market reports in the last five years, they may have gained 35% or more of the market share. e.9

As indicated by countries such as Bangladesh, Thailand, and Sri Lanka, the recent rapid spread of smaller-scale machinery has increased the productivity of agricultural and other rural resources. First, the purpose for introducing this topic is to again substantiate the different actors involved in a system to effectuate optimal social innovation. Like as in Savvides Model (Figure-1) in Bangladesh and in other places where rural mechanisation has impacted a lot of lives a synergy is seen between local markets, farmers, tillers, banks thus bringing on synergy between both organisations and society at large. Secondly the purpose was to open up the policy debate on rural mechanization rather than examine detailed technical issues thereby ushering the change through social innovation processes. The paradox then is— how is it that even with large government support, investments in the research and development as well as in the manufacturing of 2WTs, and the sizable potential for small scale equipment to increase the intensity of use of agricultural and other resources, that the spread of smaller-scale equipment has been so low in India? However, it can be suggested that part of the explanation is that agricultural mechanization in India has been largely dominated by the corporate manufacturing sector. In particular, the indigenous 4WT industry has seen the entry in the last decade of multi-nationals such as AGCO/ New Holland, John Deere, and Deutz Farh. India became the largest manufacturer of 4WTs in the world in the late 1990s, yet it was accompanied by a neglect of the machinery requirements of cultivators and other rural entrepreneurs in rural areas, especially in the poverty areas of eastern and central regions of India. Consequently, for the sake of this review of the long term sustained spread of smaller-scale equipment in the intensification ofagriculture and the rural economy, surprisingly India has limited knowledge to share, although that is may now be changing. From Savvides (1979) view it can be said that proper synergy relating to agricultural mechanisation was not there in India because of a lackof cohesion of government policies and private corporate in India.If proper doles and incentives would have been given to the farmers along with maybe a tax cess to the private 2WT manufacturers maybe a much better impact of agricultural mechanisation would have been felt in India.

In South Asian countries, the spread of smaller-scaled equipment, especially those powered by diesel engines up to 20 HP, has been accompanied by the intensification of agriculture and other rural economic activities. The spread of small-scale equipment has resulted in widespread mechanization of the agricultural sector. It has also been accompanied, in most cases, with some workers leaving rural areas and finding employment in urban areas and in the in the overseas remittance economy. In many areas shortages of labor at peak times have led to substantial increases in real rural wages. In regions where smaller-scale mechanization has taken place, there has also been a growth of rural industries and strong linkages with the broader national economy. Whether by design or not, it appears that markedly different patterns of smaller-scale rural mechanization over time have led not only to agricultural production increases, but also to broad-based rural and economic development.

As these patterns of smaller-scaled rural mechanization have taken place in today's global economy, they cannot be portrayed by the proponents of larger scale commercial agriculture as an outdated romanticization of small holder agriculture. It is our hope that there will be increasing interest in the "silent and hidden" revolutions of the spread of smaller-scaled equipment and that broad-based rural development, such as worthwhile rural employment, careful and intensive use of water and energy sources, will again become important goals of economic development. There is now empirical evidence on a grand scale that shows it can be done.

Social innovation in this case can be the need of the hour as it can be argued that the plant breeding institutions of the Consultative Group on International Agricultural Research (CGIAR) network are caught in a path dependent technological trajectory in which plant breeding is seen as the priority technological way forward in addressing agricultural problems (Hogg, 2000). This chapter supports that view by arguing that, without the rural engineering inputs, and subsidies and guaranteed prices to agricultural crops in some cases, the high yielding varieties would not have been able to express their potential. However, this did not lead to a concentration on water management, agronomy, and other rural engineering issues, which can be mitigated through social engineering/innovation but rather a preoccupation with funding plant sciences at the cost of other technological priorities such smaller-scale rural mechanization for agricultural intensification and rural development entails.

OTHER EXAMPLES OF SUCCESSFULL SOCIAL INNOVATION ENDEAVOURS IN INDIA

A Case of Gram Vikas (Orissa) (Pertaining to inequality) founded in 1979 in the state of Orissa, Gram Vikas delivers comprehensive water and sanitation systems by working together with beneficiaries in villages that have limited access to such infrastructure. The goal is twofold. First, Gram Vikas' unique approach to rural development issues, in particular through its flagship Movement and Transformation Network for Transformation of Rural Areas (MANTRA) program. The organization, along with its founder and Executive Director, Joe Madiath, has received numerous social venture awards, including the Ashoka Change makers Innovation Award, the 2007 Skoll Award for Social Entrepreneurship, and the 2006 India NGO [Nongovernmental Organization] of the Year Award. The partnership between Gram Vikas and the Comprehensive Rural Health Project (CRHP), the target organization in the study, is one of the best-documented ongoing partnerships in the context of social innovation in India.

Both of these organizations operate in the rural public health sector in India, albeit using different approaches to address the root problems of access to better sanitation and health in village areas. Gram Vikas, which means "village development" in both Hindi (India's official language) and Oriya, the local language in Orissa, was originally formed to address the needs of the so called adivasis, or tribal minorities, of the state. After an initial period of success addressing the intertwined problems of alcoholism and debt within these communities, Gram Vikas began to get involved in other areas of rural development, including education, health care and sanitation, income generation, and small-scale energy production through the development of biogas generators. In particular the company's biogas program became very successful in the 1980s when the government of Orissa approach Gram Vikas to expand what was a nascent effort to bring energy to rural areas; between 1983 and 1993 Gram Vikas built over 80% of the biogas generators in the state, representing 55,000 individual units, while using only 15% of all the public funds allocated by the government in support of biogas projects. While Gram Vikas' biogas program was very successful, senior managers within the organization felt that it did not adequately address the fundamental problem of inequality in Orissa, and, further, it did not allow the organization to work with the really exploited section of the rural population – the extreme poor. In the course of a period of reflection and experimentation in the early 1990s, the biogas program was "spun off" into numerous smaller companies and the organization shrunk in size from 1000 staff members to less than 500.

During this period, Gram Vikas developed a study of rural development problems and found that 80% of the morbidity and mortality in rural Orissa could be traced to the poor quality of drinking water. A direct cause of poor water quality was the unsanitary habits around human waste disposal. The organization thus began an initiative covering 337 families in five pilot villages to bring water and sanitation services to rural villages (Gram Vikas, 2002). This program, known as the Movement and Action Network for Transformation of Rural Areas

(MANTRA) is now the foundation of Gram Vikas' activities and its most powerful social innovation. MANTRA begins with the starting assumption that water and sanitation services are not privileges exclusively reserved for the most prosperous, highest-ranking, elements of urban society; rather, they are a right and resource to be equally shared among all members of a community, regardless of social position or geographic location. Nevertheless, the prosaic reality of life in rural Orissa belies this aspirational ideal: even to this day – after 17 years of work on the problem by Gram Vikas and other NGOs as well as continuing work on the problem by the state government for decades – less than 20% of the rural population in Orissa has access to protected water, less than 1% to a piped water supply and less than 5% to sanitation facilities (Gram Vikas, 2008). For Gram Vikas this seemingly intractable problem presented an opportunity. By working to address the problem of poor (or nonexistent) water and sanitation facilities, the organization could simultaneously address the deep-seated problems of poverty and social exclusion in rural Orissa. MANTRA was therefore developed as a program which goes well beyond simple infrastructure development for water and sanitation:

MANTRA unites communities to overcome barriers of social exclusion. Water and sanitation, as an entry point activity in new settlements, is not only a vehicle for improved health, but also a way of transforming hierarchical chaste and gender based exclusion into equitable inclusion At the surface level, MANTRA delivers concrete water and sanitation infrastructure to villages. Gram Vikas ensures that all the families in a MANTRA village will have access to the same minimum level of products and services, including: (1) toilets and bathing rooms in every house; (2) 24-hour piped water supply to the toilet, bathing room, and kitchen of every family; and (3) the construction of a water tank as a community asset (Gram Vikas, 2008; Keirns, 2007). Beyond this, MANTRA is guided by five Core Values – Inclusion, Social Equity, Gender Equity, Sustainability, and Cost Sharing – which link in fundamental ways to the broader social mission of "equitable inclusion" which Gram Vikas espoused. o achieve "equitable inclusion" in MANTRA villages, Gram Vikas lays out two primary conditions, each of which encompasses different core values. First, villages join MANTRA only through an "all or none" scheme. Either 100% of the families in a village join the program, or no families join. There is no in-between. In this way, Gram Vikas emphasizes the value of "Inclusion" as a core value. This requirement is highly related to the values of "Social Equity" and "Gender Equity" as well, and these are manifested in villages by representation of all sections of the community in village decision-making processes and equal participation of men and women in community level decision-making and control.

Second, to ensure the financial and operational stability of the water supply and sanitation installed, all families must participate in the scheme by contributing, on average, 1,000 rupees towards a "corpus fund" which goes towards maintenance costs and expansion of the water supply and sanitation system once it has been installed. This condition is most closely 15 tied to the two core values of "Cost Sharing" and "Sustainability", and is based on the principle that the poor can and will pay for development services, and that the beneficiaries of MANTRA themselves are reliable sources of revenue for maintaining the water and sanitation systems.

THE TRANSFER ATTEMPT

While MANTRA started small, initially in 5 villages covering 337 families, the program has grown since 1992 to become Gram Vikas's central program around which the vast majority of the organization's extant activities are organized. As of March 2009, MANTRA was operational in approximately 700 villages covering nearly 45,000 families and a population of over 240,000 people. Most of this population was within Orissa but a few scattered projects have reached neighboring states as well; Gram Vikas's goal is to cover 100,000 families by 2010 (Gram Vikas, 2009). With the maturity of MANTRA, Gram Vikas's leaders sought to increase its impact beyond the general area of Orissa. Joe Madiath, the Executive Director, in particular saw the organization's mandate as being much broader: Part of this mainstreaming effort at Gram Vikas involves developing partnerships with other organizations which might be able to leverage the MANTRA model and Gram Vikas'sunique approach to rural development. Such networking and outreach activities constitute a "core strategy for expansion" of MANTRA in the years to come (Gram Vikas, 2008).

Indeed, in mid-2008 the organization hired a full-time, senior-level "Expansion Manager" charged with growing MANTRA outside Orissa by partnering with other organizations, both within India and internationally. The reason Gram Vikas was dealt with so elaborately as it is a perfect example which could be emulated by every state in India. The exact strategy can be replicated in unision with governmental and private enterprises so as to make the reach and impact more extensive. Another reason for giving such important leverage to this particular endeavour is that Gram Vikas affected and impact the lives of poor people both intrinsically by concentrating on sanitation and extrinsically by providing a medium for providing energy at a much lower cost through bio gas generator.

The case of Gram Vikas is a perfect example of synchronicity between the different actors involved in a system be it government, private NGO's etc to bring about a successful social innovation.It again reiterates the fact that instead of social innovation being a one-step shop it should rather be envisaged as a complex interaction between the different stakeholders involved in that system as per Savvides (1979).

SOCIAL INNOVATION THE FUTURE OF THE ECONOMY

It is often said that today we live in the world of Joseph Schumpeter, who highlighted the cycles of 'creative destruction' animating capitalist economy. The Austrian economist notably pointed to two renewal factors: technological innovation and the role of entrepreneurs. Technological innovation can take on several forms: product creation, new production processes, new organizations of production, new markets or new source of raw material or energy. And the entrepreneur is precisely the one who endeavours for innovation, striving to meet the challenge with his drive and achieve success.

As for business and management models, they have long risen to the point of now being on par with technological innovation. The art of organizing manpower and of skillfully streamlining interactions within the workforce is core to the creation of value. Some economists go further, by asking whether social innovation could play a similar role tomorrow.

In 1970, James Taylor conceptualised social innovation as "new ways of doing things in order to meet social needs." It can involve two types of stakeholders: activists, and as in Schumpeter's analysis, entrepreneurs. Whether its commitment is with charity or with social emancipation, the action of the former is traditionally played out *despite* the market, in its interstices. As for the latter it is quite the opposite: their ambition is to *expand* the market by bringing their business to it, either by competing with existing players, by offering new services or new products, or by targeting new customers.(c.f Paris tech Review,2011)

Profit vs. Non-Profit: About Dated Distinction?

For a long time, the distinction between *profit* and *non-profit* has had the trappings of obviousness: it was so naturally self-evident that questioning it made no sense. At the most a few contact areas could be pinpointed such as the existence of forms of capitalism concerned with their social impact, from pioneers like Frederic Le Play to the social doctrine of the Church (in the late nineteenth century) and today's CSR. In addition, as early as the 1950's, sociologists like George Friedman have emphasized the enterprising character of activists, the professional qualities they display, and the managerial and organizational capabilities that are required to run an organization.

But in essence, these two worlds diverged in their purpose: it was either making money or helping others. However, in the course of the last ten years this distinction has started to fade out. The new forms of social entrepreneurship that are emerging today need to be scrutinized because they may well prefigure some of the aspects of tomorrow's economy.

As early as 1994, Peter Drucker posited that "non-profit" was but a legal term that merely means that under U.S. law these organizations do not pay taxes: whether they are directed towards profit or not has no impact whatsoever, "neither on their function, nor their behavior."

All things considered, it would not be the first time. The mutual insurance companies historically founded by the workers of the nineteenth century were the very womb where social insurance systems of the present day were born – the latter being one of the pillars of modern capitalism, as in absorbing significant financial flows to pay millions of people, they provide consumer society with consumers alleviated from worrying about the next day.

More recently, the development of *open source* systems and the fascinating economic uses of free services have shown how the profit economy could revitalize itself by incorporating non-profit exchange. Networks like Facebook have revealed that social interaction has economic value. Yet the distinction between business entrepreneurs and social entrepreneurs was precisely based on these diverging finalities or outputs. What happens with such a differentiation if the creation of social ties is to become the core for new economic activities?

SOCIAL CREATIVITY AND ENTREPRENEURSHIP

In a conference held in Paris in November 2011, Arnaud Mourot, managing director of Ashoka for French-speaking Europe, told an original story which showcases the interpenetration between the two worlds. In India, an NGO which funded cataract surgery suddenly saw its funds dry up. While not very expensive, many families were unable to afford it. Then an American volunteer had the idea to have them pay anyway, but based on what they could give: it appeared that they could afford a budget of about fifty dollars, and on that basis what the NGO was able to build was not aid from a charity, but a business model. This volunteer turned into a contractor, manufacturing intraocular lenses in large quantities. He now runs a profitable company and has contributed to restore sight to four million people. So, at once, one has profit *and* non-profit.

Large companies are taking keen interest in the "bottom of the pyramid", the socio-economic group that is both the largest and the poorest, who represent 2.5 billion people and that, regardless of its poverty, constitutes a substantial proportion of global purchasing power. Almost nobody had truly measured its potential until the famous article by C.K. Prahalad and Stuart L. Hart, "The Strategies for the Bottom of the Pyramid" was published on the Internet and then by the *Harvard Business Review*; it then went on in expanded form to become a best seller. While it suddenly fell in the category of profit stakeholders, this economic segment remains associated with practice characteristic of non-profit, which may bring the two groups to mingle, as the example of cataract surgery has shown. In this particular case, the success of the social entrepreneur is a function of his ability to mutate into a regular entrepreneur, while the businessman he is would never have arisen without the volunteering spirit that drove him at the beginning of his journey. Both postures are inextricably intertwined.

In a recent communication, Julien de Freyman (ESC Troyes), Katia Richomme-Huet (Euromed-Marseille) and Robert Paturel (Université de Brest) have carried out a systematic study of the personal stories of businesspersons who, throughout their career or within the framework of a single activity, have experienced both postures. Entrepreneurial reality is complex, they found, because a middle ground reconciling economic and social motivations, societal entrepreneurship, has now added itself to the equation where there were previously only two extremes – traditional entrepreneurship and social entrepreneurship. Such an approach enables them to explore the various links between the three forms of entrepreneurship.

Thus a new template is emerging for business types, marked by a search for meaning. Kevin Cardona, in an research paper published in 2006 on the Observatory of alternative management, noted the emergence of a different paradigm, dominated by themes of self-realization and the refusal tasks that are at once imposed and meaningless. "If a company is in itself a small world of sorts, it is also a perspective on the world, one of its reflections, and one of the faces of society. Modern entrepreneurs are now aware of this responsibility and wish to part ways with a posture of mere consumption of the world." Business people driven by a commitment towards social innovation would then just be the most visible, and perhaps most radical portion, of a new business world.

The Search for an Innovation

Social innovation can thus be regarded as an experimental space which provides leeway for the renewal of services (commercial or public), but also of the main forces (the businessman, utility, and value) that drive our societies.

It needs to be studied, analyzed and appraised. However it's not that simple, for various reasons. First, right away integrating the concept of externality, that is to say, of collateral results that are impossible to measure is characteristic of these innovations. In the longer run, they may well develop a social efficiency that could go beyond the agenda of the initial project, by being a catalyst for social change and by contributing to the emergence of a new development model. But it remains difficult to reduce their value to statistics that command public policy and investor interest.

How can greater recognition and development of such experimental spaces be achieved? Speaking at the aforementioned conference, Romain Beaume, professor at the Ecole Polytechnique (Chair of Innovation Management), rightly pointed out that for over 100 years, technological innovation has been the center of attention: be it through tracking, promotion, training of stakeholders, creation of dedicated private or public structures, tax policy, nothing has been neglected in fostering it. In contrast, social innovation is a practice at once ancient and very recent in the sense that its value has only been noticed in recent years. Institutions and economic tools liable to support its development are still of a rudimentary nature.

However models are emerging and new spaces appear. Speaking at the Paris Symposium of late November, Romain Beaume suggests that the steps taken towards social innovation relate to *design thinking*, which was developed at Stanford University and is now the core activity of companies like Ideo. While industrial design aims at optimizing the function, the value and the appearance of a product, the notion of design thinking applies to "situations of use." Resting on a method based on user-centered innovation (*human centric design*), it involves diverse fields: services, marketing, strategy, forecasting. And with this we truly have reached one of the central themes of social innovation: to play around new interactions and benefit from them, turning them into the engine of an exchange dynamic – in a word: to give them value.

So, if social innovation can become an intellectual and methodological model, could it in turn end up trapped into formulas and methods? Not unlike classic entrepreneurship, it is mainly driven by unusual characters, closer in kinship to the adventurer or the navigator than to the manager. Denis Harrison, former director of the Centre for Social Innovation at the University of Quebec at Montreal, emphasizes the part played by creativity in social innovation, not only respecting its overall objective of advancing the well-being of individuals and communities, but also in relation to its "outstanding, non-standard character."

While it is fascinating to observe social innovation in action, there is no certainty that it can be reproduced, nor that one successful experience can be set as a solid reference. However, it is now crucial to promote its development, which by no means should limit itself to allowing initiatives to flourish on their own. Just as important is the challenge of supporting that development, especially by paying attention at the time of the rise, when momentum is being gained. This is where professionalization and training prove to be decisive. But how can social innovation be managed?.(c.f Paris tech Review,2011)

Managing Social Innovation

The question of managing social innovation was first posed by major foundations as they searched for projects that would be led by sensible, credible figures. These foundations are trying to develop intern capacities, as they must work both on identifying the most creative innovators and on helping them to develop their projects in an efficient way. The challenge is to keep creativity alive *and* to check that funds are spent as rationally as possible.

Stephen Huddart, who chairs the JW McConnell Family Foundation, insists on developing a capacity for social innovation within foundations and charities. This boils down, in short, to tuning in and empowering oneself and one's company to notice projects and nurture them. Stephen Huddart is a notable speaker in the seminar organized by Frances Westley, Chair of Social Innovation at the University of Waterloo (Canada) and co-founder of the Waterloo Institute for Social Innovation and Resilience; for her part, she asserts that the crucial element in a project is to achieve sustainability.

Large foundations are facing issues that can be compared to the daily challenges of business angels. Risk-capital management is basically a mix of gambling and rationality. Part of this business is to leave innovators lead projects their own way, be they more qualified to innovate than to manage a company. Meanwhile, risk capital managers have to get results and report to investors, so they also have to intervene within the start-up companies into which they decided to invest. The same occurs with foundation managers when they report to their sponsors. More than in any other field, decision-making requires taking different perspectives on the same project and being able to make strong choices.

This capacity to deal with several points of view and several logics is a crucial competence. It is the heart of a recent training project launched by HEC Paris, around alternative management. The aim is both to train efficient managers who will work in the social innovation field, and to educate future corporate managers with methods and experiences from the NGO and social work field. It's basically a cross-fertilization initiative, aiming to create a dialogue between different worlds. Founded in September 2006 by Professor Eve Chiapello, aims at anticipating evolutions in management and at deepening alternative approaches so that its students make sure they will be a step ahead in the world of tomorrow. Students from this Major may later steer towards different professional realms, from Goldman Sachs to field work in NGOs, but they will have one thing in common: they learned to develop a pluralistic vision of management practices.

Eve Chiapello regards the history of management as having built itself around a state of permanent questioning: "Today we are witnessing a proliferation of initiatives and proposals to change the world. The concept of sustainable development is a symptom of this situation: few people had heard of it ten years ago, and now it is taking the center stage! We must make sure that our students are fully in touch and awash with this effervescence that is teeming with novel ideas." Social innovation, thus, would be one of the elements leading to what Chiapello sees as the reconstitution of a "reformist nebula". Here, Schumpeter would have seen the beginning of a cycle of innovation: the invention, on the fringes of the current central model, of tomorrow's economy.(c.f Paris tech Review,2011)

MITIGATION OF CLIMATE CHANGE THROUGH SOCIAL INNOVATION

In a country like India with a constant land mass but with burgeoning population it is extremely imperative to make the livelihood of people associated with the aspect of agriculture, fisherman, becomes sustainable. For that adaptation measures either in the new form of technology, economy, social or cultural change are needed. For instance in a research done on the fishery community in and around Bombay by Gupta & Senapati certain amazing insights came out relating to social adaptation /innovation.

Measures To Mitigate the Effect Due To Climate Change

Most of the innovations were cultural by nature which actually included the fact that while previously fisherman used to go out after a certain month after performing a particular puja now they go out to fish nearly 365 days a year to mitigate the effect of climate change on fish yield. Technologically also instead of many small boats going to capture fish one big trawler is used to increase the fish catch and reduce cost on the part of the individual fisherman. Some has been done but still lot of steps need to be implemented for creating awareness about climate change. NGOs, government welfare schemes should all direct their effort to mitigate the negative effect owing to climate change then only a proper social innovation can be said to happen.

Car Clubs and Electric Vehicles

As an example of technological innovation and social innovation, we look at two very different niches, both of which have great potential in reducing emissions from personal transport. The technological innovation is electric vehicles, and the socially focused innovation is car clubs, while both could play a significant part in making personal transport more sustainable, they are treated very differently in policy and planning.

Electric Vehicles

Bergman avers that Electric vehicles (EVs) are not a new invention; they have been around since the late 19th century. However, their high cost, especially of the batteries, compared to the petrol powered combustion engine car left them behind. In recent years there has been a renewed interest in EVs due to the lack of tailpipe emissions, reducing air pollution, and potentially reducing greenhouse gas emissions from driving, if the electricity is from a low-carbon or renewable source. On the other hand, the electric car vision requires continued development of roads and other transport infrastructure and does little to change behaviour or the high energy use car culture.

In the UK, electric cars have not so far- managed to capture the market, with only a few thousands on the road despite government support and significant financial backing. The call from the Committee on Climate Change for 1.7 million EVs in the UK by 2020 is considered extremely optimistic by some (Vaughan, 2011).In 2009, the UK government laid out a £250 million strategy for a 'revolution in Britain's road transport network based on ultra-low carbon vehicles' (Jha, 2009); more recent reports are of a '£450 million strategy to create a market for ultra-low carbon vehicles' (EEN, 2010). As part of this, £43 million were set aside from the beginning of 2011 until the end of March 2012 for an incentive of £5,000 for purchases of cars producing 75g CO2/km or less – enough for 8,600 vehicles. As of July 2011, only 680 EVs were purchased under the scheme (EEN, 2011). Other investments in the strategy include £30m to start installations of electric car charging points (EEN, 2010) and a £25m EV trial (Jha, 2009).Emissions savings from electric vehicles are highly dependent on the means of electricity production – usually considered to be the average emissions of the national grid. Ecometrica (Davis, 2011) calculates emissions of 75 g CO2/km for EVs in the UK, compared to only 12 g CO2/km for France, which has a grid which is much lower in carbon intensity. Davis estimates the emission reduction from the (£43m) EV grants, assuming the full sum was used to subsidise 8,600 vehicles, which would displace 'a mix of the most efficient diesel and petrol cars on sale' (ibid.). He calculates savings of 7,483 t CO2y -1 (tonne CO2 per year), but acknowledges that different assumptions can lead to very different results, and offers this calculation as a 'worst case scenario'. This translates to approximately ~1 tCO2y -1 savings per electric vehicle purchased, or ~50% of the emissions of the average UK car.(Bergman)

Transport

Energy for transport has come to form a major part of the energy demand. Fuelled with hydrogen, fuel cell vehicles (FCVs) are more efficient than the internal combustion engine vehicles that dominate the current transportation fleet. However, the production of hydrogen requires more primary energy than diesel or petrol. Nevertheless, the overall energy (and CO2) balance is positive. Another very important characteristic of FCVs is their contribution to reduce other emissions such as NOx and dust, which results in greatly improved (urban) air quality.(Faiij,2002).

Energy System

Production of hydrogen and power from coal with CO2 removal and storage; fossil fuels, in particular coal and methane derived from coal beds, still play a key role in meeting the energy demand. Sustainable and competitive use of fossil fuels is possible with advanced technologies such as gasification, high temperature gas separation and advanced power cycles. Such systems allow for cheap and efficient removal of CO2, resulting in carbon neutral power and hydrogen. Energy efficiencies of these systems are high (50-70 per cent) when applied on a large scale (e.g.1000 MWth input).(Faiij,2002)

Built-Up Environment

Energy-efficient dwellings: If no measures are taken energy use in the built-up environment will increase drastically due to more luxurious standards of living and larger dwellings. Furthermore, these houses are built in suburban environments making application of district heating very difficult; increased energy efficiency of dwellings (in particular heat demand) is therefore very important. High levels of thermal insulation, heat recovery equipment and widespread application of solar heating keep the final energy demand of the built-up environment within acceptable limits. The remaining heat demand is met with efficient heat pumps.(Faiij,2002)

After having looked at material efficiency as a significant option for reducing greenhouse gases, we will now focus on another important, evolving area of technology: information and communication technology (ICT). Obviously, information and communication technologies have changed the world enormously in the last decade. Some authors refer to ICT as a major resource for increasing the eco-efficiency of many activities. (Slob & Lieshout,2002)

Transport and Mobility

Slob & Lieshot (2002) avers that the use of ICT can promote sustainability in the traffic and transport sector in a number of ways:

1. By optimizing the use of the infrastructure (including promotion of the 'modal split');
2. By optimizing the logistics chain;
3. By reducing the pressure on mobility through alternatives (teleworking, teleshopping, telelearning);
4. With intelligent vehicles and monitoring of cargoes.

According to Slob & Lieshot (2002) the optimization of the infrastructure does not automatically lead to a reduction in CO2 emissions. More efficient use of the infrastructure could help to spread traffic through the day, the assumption being if the traffic flow increases there will be greater emissions of CO2. Promoting the modal split is a way of stimulating the most efficient form of transport from an energy perspective (especially transport by water compared with transport by road). However,(Slob & Lieshot,2002) contends that ICT mainly further reinforces the competitive advantage of the door-to-door approach of road transport, in part because the use of ICT increases the opportunities for customized service.

Furthermore they reiterated that optimizing the logistics chain fits in with the *Just in Time* approach. Greater control of the entire transport and distribution process means that smaller inventories need to be held, and consequently smaller storage systems are needed. With the use of a comprehensive logistics system, the utilization of capacity of goods transport can be increased: fewer empty runs and optimization of the length of trips.(Slob & Lieshot, 2002)

But in a recent study Transport en Logistiek Nederland (TLN) pointed to the likely increase in the number of trips with small vans if e-commerce really takes off (TLN, 2000). In the next five years TLN expects an increase of 38 per cent in the number of trips for freight transport. Of this 38 per cent increase, 21 per cent will be 'autonomous' growth and 17 per cent due to developments in e-commerce (8per cent growth in the Business-to-consumer sector, 9 per cent in the Business-to-Business sector). A scenario study by jointly by the ministries of Transport, Public Works and Water Management, Economic Affairs and Housing, Spatial Planning and the Environment concluded that with the conscious use of ICT tools- CO2 emissions could decline sharply but would probably still remain above the target of 168 billion kilograms (Nederland digitaal, 2000).

Teleworking leads to substitution of commuter traffic. The savings could rise to 40 per cent of the number of trips per week (ICT & Sustainability, 2000; Forseback, 2000). The increased use due to the car becoming available generally seems to be less than the savings (Puylaert et al, 1999). In other words, the sum of the effect of a car being freed up for secondary purposes (social and recreational traffic), other work-related movements or instigation of new commuter traffic is less than the savings achieved. In combination with the assumption that the house is a more energy-efficient place to work than the office (ICT & Sustainability, 2000), large-scale introduction of teleworking could make a positive contribution for reducing CO2 emissions. Besides teleworking, teleshopping can also save trips. Up to now the expectations for teleshopping have scarcely been converted into quantifiable data. Following the TLN study, a certain degree of scepticism is therefore justified about the direction these developments will take.

Industry

There is some literature on the effects of ICT at macro-level, but no literature was found for specific sectors of industry. What follows, according to (Slob & Lieshot,2002) is based mainly on their own forecasts of those effects. ICT could have two major influences on industry. On the one hand, optimization in companies and collaboration in chains so that energy and materials can be used more efficiently. On the other hand, ICT could reinforce the existing trend of the growing importance of services in the economy, because services can be provided via e-commerce and tailored to the individual customer. Transport activities relating to industry were not considered by the above researchers.

(Slob & Lieshot, 2002) predicted that greater accessibility of information and the speed with which information is exchanged will make it easier for companies to share information worldwide about the environment and to monitor flows of raw materials and waste substances furthermore this information so essential for chain management, where the various steps in the production process, from raw material to product to waste, can be linked in a way to keep pollution to a minimum. In this respect, according to the above researchers ICT acts as a facilitator for collaboration between suppliers and customers and hence can help to optimize the entire chain. This aspect will have a positive effect particularly for the substances emitted to the environment and not so much for energy consumption. To grasp these benefits a novel organizational structure setting out the protocols for information exchange (method of exchanging information, infrastructure, assurance of reliability, confidentiality, etc.) is needed. Apart from this various industrial production processes can be made more intelligent and can be better monitored with ICT applications. This could generate savings of raw materials and energy, although for the time being we do not estimate this effect as being very great. Production processes in companies are already largely optimized. ICT could make a minor contribution to this.

Finally, as (Slob & Lieshot, 2002) avers ICT can help to increase the transparency of the market for raw materials, waste and residual products. For instance, as per them industrial ecological complexes could be formed at local level, in which the waste from one company becomes the raw material for another, or in which companies swap heat and electricity with each other. But ICT can contribute little to the creation of these complexes: it is not so much the 'market' that is the problem but rather the need for collaboration between companies, which poses a number of dilemmas, such as the creation of mutual dependency, the division of costs and benefits and the risks for business operations. The introduction of ICT is expected to have at best a modest impact on energy consumption.

The trend towards the increasing importance of services in the economy has been apparent for years. Slob & Lieshot (2002) further questions, as per how the industrial sector will develop in relation to the service sector. Will we have a full service economy in 2050 or will there will still be substantial industrial activity? From the ICT perspective, what can be said is that ICT can make a significant contribution to the creation, sale and delivery of services. The literature (Bilderbeek et al., 1998; Miles et al., 1999) shows that ICT plays an important role in service innovation. Many new services are born from ICT applications for instance the 'booming business' of e-commerce is totally based on ICT applications. It is therefore likely that ICT will reinforce the trend towards the service economy. (Slob & Lieshot, 2002)

What does this mean for the likely environmental effects? Generally speaking, environmental scientists take a very positive attitude towards services, based on the idea that the material component in services is smaller than in products. However, literature suggests conflicting issues to mean that maybe an increase in service may not always lead to a decrease in emissions (Nijhuis et al., 2000). After all, services often also need products (for example, computers when we are talking about e-commerce), and since people have to do the work there is often a significant transport component involved in getting the service providers to the client.

Another aspect that emerged from the study of (Slob & Lieshot, 2002) was that the 'rebound effect' of services can be considerable. Simple access to the purchase of services can easily lead to far more services being bought than would be necessary purely on the basis of substitution. The volume of demand hence increases, as do the related environmental aspects, so savings can be cancelled out. Hence as per (Slob & Lieshot, 2002) it cannot be simply assumed that an increasingly service-oriented economy will automatically lead to reductions of emissions or energy saving.

Agriculture and Food

In the previous section (Slob & Lieshot, 2011) only considered the consequences for industry but there is no reason to believe the mechanisms described above should work differently for the food industry. Precision agriculture is a promising application of ICT for the cultivation of crops in agriculture. Precision agriculture is a form of farming where growers respond to the natural variability of the soil with the help of different technologies. By sowing, tackling weeds and diseases, applying nitrogen and harvesting according to the requirements of a specific location it is possible to improve the quality of the harvest, increase yields and curb harmful effects for the environment.

Satellites are an important element of precision agriculture, as also GPS (Global Positioning

Systems) objects, whereby case harvesters and sowing machines, can be followed and steered. The yield from a plot is measured using a harvesting machine fitted with a yield meter and a GPS. The result is a yield map, which shows the yields for each location in the plot of land. The differences in yields are explained, for instance by differences in soil composition, ground water level, etc.

The data acquired in this way are processed and converted into charts for manure spreading, spraying and sowing. With the aid of sensor technology, muck spreaders, sprays for pesticides and sowing machines can adapt the doses to the exact needs of a particular point in the plot. All the calculations are entered in a single central computer, which helps the farmer to determine the optimal time and route for harvesting. Precision agriculture increases productivity, improves the quality of the crops and the efficiency and effectiveness of the use of resources such as seed, manure and pesticides (Nijhuis, 1999; Nijhuis et al., 2000). Precision agriculture therefore contributes mainly to the efficient use of raw materials and can also help with more efficient use of energy. It may be said that the effect on energy consumption may not be particularly large. Processes in the horticulture and livestock sectors are already heavily mechanized.ICT applications could make these processes even smarter and further optimize them and the corresponding effect on energy consumption can be particularly optimal.(c.f Slob & Lieshot,2002)

CONCLUSIONS ABOUT THE RELATIONS BETWEEN ICT AND CLIMATE CHANGE

The field of ICT is developing much quickly technologically as compared to its social context. As per (Slob & Lieshot, 2002) it is basically the use of ITC in socialmcontext which ultimately determines the implementation of ICT. Therefore, the social context is a key factor for the implications of ICT developments for climate change. Hence if we want to really use the capabilities of ITC to mitigate the threat from Climate change current policies and arrangements among the different tiers of actors involved in the process has to be changed.

As per Savvides model (1979) different stakeholders occupying different peripheries within a circularly envisaged innovation system has to be involved, which actually questions the current centralized arrangement in decision making. This approach as per (Slob & Lieshot, 2002) directly addresses the dilemma of 'central steering via direct regulation and market incentives' versus 'co-production'. It may be clear that in this dilemma it is better to choose a participatory approach that is directed towards involvement of various societal actors (co-production).

The tentative policy options that can be adopted if we want to gain the maximum benefit from the energy-saving effects of ICT applications, the following measures can be helpful:

- Monitoring the use of ICT in society, which would also have an important function in identifying the following aspects; (Slob & Lieshot, 2002)
- Influencing technology-behaviour interactions; preventing rebound effects; ensuring that the infrastructure is adequate;
- Providing information to users and ensuring there are adequate organizational models for information-exchange and feedback; (Savvides, 1979;Slob & Lieshot,2002)
- A mix of technological and social innovation for creating a synergy between intelligent appliances and desired rules and regulations.

But again the question that becomes of primal importance is who to take the initiative to implement the various conceivable and possible arrangements: the government or the private sector?This dilemma can be resolved keeping in mind Savvides Model (Figure 1) whereby all the stakeholders be it government or private can participate in unison or separately to affect the society at large.It may be either in the form of technology or creation of new law or in the other forms of basic societal arrangement. The reason behind this is the fact that though ICT can somewhat contribute to a reduction of energy usage among industrial sectors through effective usage of it in transport and traffic yet a sizable dent say in the range of 70-80% in energy emissions is not possible unless due consideration is given to new institutional arrangements, new organizational and information structures, infrastructure and in man machine interface. The future interaction between the technology and the user (the rebound effect) is particularly difficult to predict. It is precisely this interaction that will account for the ultimate effect on energy consumption. Additional or alternative use of the technology could turn a potential benefit for energy consumption into a disadvantage. Intelligent appliances can be used to direct user behaviour. But there is still little known about technology-behaviour interactions. More research on this subject is needed to increase the understanding of this phenomenon and to come up with suitable policy options to guide the phenomenon. (Slob & Lieshout, 2002)

Hence from this it can be argued that increasing service centric economy (Slob & Lieshout, 2002) may not be the end to climate change woes instead can actually lead to a increase in the pollutant emission. Though service sector can create some change in total emission but will be unable to have any effect in decreasing energy consumption.

FUTURE RESEARCH DIRECTIONS

Not only Technological answers but also social research, involving the interaction between the different stakeholders as enumerated by Savvides (1979) are the first step towards exploring strategies for a climate-neutral society. They serve to inspire marginable futures. At this juncture we can safely predict the main issues concerning climate change which are clubbed under as follows-

1. Climate averse to climate safe- listing of factors for the transition.Seperate research for individual stake holders.
2. Decision modes from centralised to decentralised.
3. Handling conflict and equity. (Slob & Lieshot, 2002)

Hence future research can lead both to development of a climate neutral society not only by new technological products but also by taking measures culturally and socially through administrative means or otherwise for effective social innovation.

SUMMARY

In summary, this paper is an attempt to extend the theories of innovation in organisational context, trying to understand social innovation with it and then correlating it with climate change literature. Initially Savvides (1979) helped to understand the continuity of organisational innovation with social innovation which again forms an important part in climate change mitigation. There is a good deal of variation in the empirical literature on bottom-up, low-carbon, social innovation. In some senses it cannot yet be said to constitute a literature, in that the individual contributions are not inter-referential. In addition, in some of the work referenced above the word ‘innovation’ is not used (Bergman et al 2010).Three What brings this literature together is not only the explanation of social innovation the focus on new social practices and institutions but also how climate change can be intertwined with socially innovative endeavour) and have varying relationships to technology (no technologies involved, use of technology to further social innovation, development of technology to further social innovation).

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Chapter 30
Moving forward a Parsimonious Model of Eco-Innovation:
Results from a Content Analysis

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ABSTRACT

Complexity of sustainability issue in operations management leads this study to determine a parsimonious model of eco-innovation. Most of research findings have been emphasized on the effect of innovation on company's economic benefits. However, there is inadequate study in respect to eco-innovation and impact to business and environmental sustainability. This is causing a lack of study on this topic. The paper focuses on determinants of drivers of eco-innovation and seeks the impact to the outcome of sustainable business performance. Content analysis is used in order to explain phenomena of eco-innovation in operations management and categorize the determinants of drivers. The unit of analysis of this study is driver or factor of eco-innovation which commonly uses in entire articles. The scope of review encompassed articles published during 1994 to 2012. Results indicate that a parsimonious model of eco-innovation was consisted of five drivers. More comprehensive and robust findings could be obtained by testing this model and broadening the scope of study.

1. INTRODUCTION

With the rapid growth of the global economy, the expansion of economic activity has exaggerated worldwide environmental problems such as global warming and resource scarcity. The issues on the environment and resources have aroused common concerns that resulted in key bottlenecks of sustainable development (Ar, 2012). Consequently, it can be observed that there is an increasing trend on firms taking responsible measures to curtail with environmental issues (Frenken and Faber, 2009; OECD, 2009). In response, companies tend to shift from conventional ways of production method to green practices such as eco-innovations (Laperche and Uzunidis, 2012; Ekins, 2010; Tyl, Millet and Vallet, 2010).

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This study attempts to provide insights towards the parsimonious model of eco-innovation by adapting five measurement constructs in green business. The principle of parsimony brings the concept of the simplest possible model should be chosen. There are many researches discussed the complexity measurement of eco-innovation, therefore, previous studies found that lack of consensus on how to measure eco-innovation. This study is adopting the simplest assumption in the formulation of a concept to identify the relative important dimensions of eco-innovation.

For today business practices, it is vital to know how firms can create and add value (environmental and monetary) to their products and services through innovation (EC, 2010). Firms can meet sustainable business performance in the aspect of economic, social and environment through eco-innovation (Olson et al., 2010; Pujari, 2006). For that reason, to show the contribution of a business to the sustainable development, this study conceptualizes the extent of eco-innovation by adapting five dimensions companies. It is also crucial to create and increase the awareness of eco-innovation among the business world. There are direct and indirect benefits for firms practice eco-innovation (Kemp & Foxon, 2007). The direct benefits for the innovator comprise of operational advantages such as saving cost from greater resource productivity and better logistics. Meanwhile, the indirect benefits for company include better image, better relationships with customer, suppliers and authorities, greater worker satisfaction, and health and safety benefits. Furthermore, knowledge and innovation can improve products and services; consequently, it improves customer satisfaction (Cobb, 2011).

Previous researchers have similar consensus on the definition of eco-innovation (OECD, 2009; Horbach, Rammer & Rennings, 2012; Carrillo, Río, & Könnölä, 2010). Unfortunately, the overwhelming majority of research has been concerned with the issues of innovation with respect to economic competitiveness rather than environmental sustainability (Steward, Wang and Tsoi, 2008). Besides, one of the literature gaps is that most researches focus on what could be termed “singular” innovations of individual products, processes or practices (Steward et al, 2008), but is lack of study examine the shift of unsustainable socio-technical activities to more sustainable ones. The indicators of eco-innovation are based on the digital “product information” sources and “new announcement” databases (Steward et al., 2008). In the other hand, Kemp and Horbach (2008) found that eco-innovations may be measured on the basis of exports data, sales data and world market shares of eco-innovations that sold as goods or services.

Not only to fulfil the immediate needs and wants of the markets and society, companies are also focusing the future requirements (Seurig, Sarkis, Muller and Rao, 2008; Linton et al., 2007). Eco-innovation has been linked to business strategy which enhances capabilities and reduces negative impact to the environment during production process, generally accepted by industry and scholars (Del Rio, Carrillo-Hermosilla, Könnölä & Bleda, 2011). Therefore, firms are operating eco-innovation to obtain the ultimate goal of sustainable business performance. Firms who have invested in eco-innovation aim to be more eco-efficient than competitors, either in the overall environmental performance of the company or in the environmental impact of the given product (Anderson, 2008). Besides reduction in negative environmental impacts, eco-innovation also have been introduced for other impact such as increase resource productivity (economic) (OECD, 2009) and to enhance the understanding of global environmental change and it’s relation to economic and social systems (Rennings, 2000). The objective of this study is to develop a parsimonious model of eco-innovation from the identification of key drivers. This paper is structured as follows: Section 2 explains definitions of eco-innovation and gives an overview literature on eco-innovation.

2. LITERATURE REVIEW

2.1. Eco-Innovation

According to Schumpeter (1934), innovation is defined as "to produce means to combine materials and forces within our reach. To produce other things, or the same things by a different method, means to combine these materials and forces differently". In addition, Rogers and Shoemaker (1971) come with another new perspective to innovation concept; innovation act as an idea, knowledge, practice or object perceived as new by an individual. In turn, innovation is all about research and development, a blend of strategic planning, marketing, project management, team work, training and innovative thinking (Türker, 2012).

Eco-innovation acts as one of the term of environmental innovation; it relates to innovations targeting at a decreased influence of innovations on the natural environment. This paper, partly adopts the European Commission definition of eco-innovation as below (EC, 2008):

The production, assimilation or exploitation of a novelty in products, production processes, services or in management and business methods, which aims, throughout its lifecycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy).

Furthermore, the European Commission linked eco-innovation to sustainability, "eco-innovation is any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy" (EC, 2008).

In general, all the definitions emphasize that eco-innovations will reduce the environmental impact caused by consumption and production activities (Horbach et al., 2012; Carrillo et al., 2010). In the organization, eco-innovations can contribute to the sustainable business performance, taking into account social, environmental and economic aspects. To achieve the sustainable performance is depends on its ability to create and maintain sustainable economic processes (Hermosilla et al., 2010).

In addition, eco-innovations can result of other economic rationales such as increasing market share or reducing costs (Horbach et al., 2012). In turn, the eco-innovation benefits the firms in form of return on investment in the technology process, which reduces material input in the production process such as energy (Reid and Miedzinski, 2008). As eco-innovation in organization is important, a competitive factor is required to predict the recent concept of eco-innovation and it's dimensions in organization. In section 3, we describe the methodology of this study.

3. METHODOLOGY

Content analysis acts as the methodology of this study, it is a method that can be used either in quantitative or qualitative way. According to Berelson, (1952) content analysis can be defined as "a research technique for the objective, systematic and quantitative description of the manifest content of communication", that emphasizes the quantitative approach. This paper conducts a systematic review of literature in the field of eco-innovation. The content analysis should come with a clear process structure (Kassarjian, 1977).

Therefore, this study follows the four-step process model derived from Mayring (2008) as introduced as follows:

1. The chosen article is delimitated and the unit of analysis is defined (article collection);
2. Formal characteristics of the article are assessed, providing the background for

subsequent content analysis (descriptive analysis);
3. Structural dimensions and related analytic categories are selected, which are to be applied to the collected article (category selection); and
4. The article is analysed according to the (analytic) dimensions (material evaluation).

In general terms, content analysis is iterative and advocates choosing the most parsimonious model for eco-innovation which is to minimize the model complexity. In this study, the scope of review encompassed articles published during 1994 to 2012. While, the drivers of eco-innovation which commonly uses in entire articles act as the unit of analysis of this study. To assure the traceability and verifiability, separate the process steps is essential for qualitative content analysis (Duriau, Reger and Pfarrer, 2007; Mayring, 2008). Referring to Neuendorf (2002), the goal of content analysis is to identify and record relatively objective (or at least intersubjective) characteristics of message. Subsequently, take account of several researchers into content analysis help to improve the validity and reliability of (literature) sampling and data analysis (Duriau et al., 2007). Content analysis is also useful to sort out the variables which related to building a theoretical framework, a theoretical foundation, conceptual models, constructed of theories and concepts. Based on contest analysis, section 4 explains the five drivers of eco-innovation.

4. FINDINGS

Regarding the phase of descriptive analysis, Table I and Table II show the distribution over the time period and over different articles is to be displayed, this provides the reader with necessary information about the literature sample.

Taking on the broad idea of Mayring (2008) who conceives data evaluation as text comprehension and interpretation by means of summary, explication, this paper found that all reviews under examination have, at least applied elements of content analysis. From the following tables, this study found that there are five main drivers are important role towards eco-innovation.

Table 2 shows most of articles reviewed in this paper were published in Journal of Cleaner Production. We also concluded that content analysis act as an effective tool for conducting literature reviews in a transparent and systematic way. The analysis found that the five drivers (regulation, technology, cross-functional coordination, supplier involvement and market focus) are important role towards parsimonious model of eco-innovation. Hence, future researchers in the field of eco-innovation/operations management/green business are encouraged to make effort on empirically examine these five drivers in their research endeavours.

4.1. Determinants of Eco-innovation

In this section, this study reviews the key factors of eco-innovation, specifically regulation, technology, cross-functional coordination, supplier involvement and market focus as they are the five key drivers that have been discussed in previous scholars (Figure 1).

4.1.1. Regulation

Today, as the pressure of worldwide to deliver products and services is growing, the policy makers and regulators are facing with a double externality when there is growing pressure worldwide to deliver products and services. This double externality means every type of innovation has to provide a positive external effect from its research and development efforts. From previous studies, regulation has been one of the important determinant of eco-innovation (Horbach et al., 2012; Beise and Rennings, 2005; Brunnermeier and Cohen, 2003). Regulation has become essential

Table 1. Descriptive analysis of article review

Reviewed Papers	Aim/ Main Topic
Sub-field 1: General reviews eco-innovation • OECD (2008) • Horbach (2008) • OECD (2009) • Santolaria et al. (2011) • Boons et al. (2012)	Linking economy, society, environment Determinants of eco-innovations by type of environmental impact Sustainable Manufacturing and Eco-Innovation Eco-design in innovation driven companies Sustainable innovation, business models and economic performance
Sub-field 2: Regulation • Brunnermeier and Cohen (2003) • Beise and Rennings (2005) • Horbach et al. (2008) • Khanna et al. (2009) • Kammerer (2009)	Determinants of environmental innovation in US Lead markets and regulation Determinants of environmental innovation The role of management systems and regulatory pressures The effects of customer benefit and regulation on environmental product innovation
Sub-field 3: Technology • Rennings (1998) • Baumol (2002) • Horbach et al. (2008) • Khanna et al. (2009) • Doran and Ryan (2012)	Towards a theory and policy of eco-innovation The free-market innovation Machine Determinants of environmental innovation The role of management systems and regulatory pressures Regulation and firm perception, eco-innovation and firm performance
Sub-field 4: Cross-functional coordination • Cooper (1994) • Pujari (2006) • Clerq et al. (2011) • Ernst et al. (2011) • Olson et al. (2011)	New products: the factors that drive success Eco-innovation and new product development Closer look at cross functional collaboration and product innovative Customer relationship management and company performance Integration of sustainability issues during early design stages
Sub-field 5: Supplier involvement • Hult and Swan (2003) • Rao and Holt (2005) • Georgiadis and Besiou (2008) • Arundel and Kemp (2009)	Research on product development and supply chain management Green supply chainlead to competitiveness and economic performance Sustainability closed-loop supply chains Measuring eco-innovation
Sub-field 6: Market focus • Day and Wensley (1988) • Kohli and Jaworski (1990) • Pujari (2006) • Piercy (2009) • Hermosilla (2010)	A framework of diagnosing competitive superiority Construct, proposition and implications of market orientation Eco-innovation and new product development Change of market-led strategic Diversity of eco-innovations with selected case studies

because it provides informative and normative content such as issue specific policies and strict guideline to all the eco-innovators and polluters so that organization understand what is required and vice versa (Doran and Ryan, 2012).

Khanna et al. (2009) argue that to induce innovation, should mere anticipation of stringent environmental regulations. The anticipation of rigid policies may lead firms become more innovative, increase competitive advantage and create barriers for competitors enter. Meanwhile, government can encourage eco-innovation by implement measurements that reduce the private cost of producing innovation (Nemet, 2009). Therefore, policy stringency has become crucial drive force for eco-innovation rather than choice of single policy instrument (Rennings, 2000).

4.1.2. Technology

A firms' technological factor is also play an important role in eco-innovation especially in the initial development phase of eco-innovation (Doran and Ryan, 2012; Horbach, 2008). Technology of eco-innovations can be distinguished in curative and preventive technologies (Rennings, 1998).

Table 2. Distribution over journals

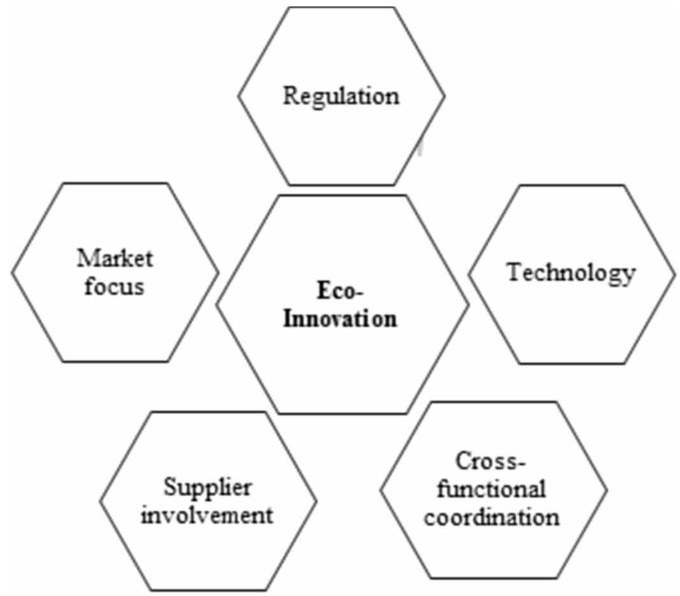
Reviewed Papers	Journal
Sub-field 1: General reviews eco-innovation • OECD (2008) • Horbach (2008) • OECD (2009) • Santolaria et al. (2011) • Boons et al. (2012)	Synthesis Report Research Policy Synthesis Report Journal of Cleaner Production Journal of Cleaner Production
Sub-field 2: Regulation • Brunnermeier and Cohen (2003) • Beise and Rennings (2005) • Horbach et al. (2008) • Khanna et al. (2009) • Kammerer (2009)	Journal of Environmental Economics and Management Ecological Economics Ecological Economics Environmental and Resource Economics Ecological Economics
Sub-field 3: Technology • Rennings (1998) • Baumol (2002) • Horbach et al. (2008) • Khanna et al. (2009) • Doran and Ryan (2012)	Discussion Paper Book Ecological Economics Environmental and Resource Economics Journal of Innovation Management
Sub-field 4: Cross-functional coordination • Cooper (1994) • Pujari (2006) • Clerq et al. (2011) • Ernst et al. (2011) • Olson et al. (2011)	International Marketing Review Technovation Journal of Production Innovation Management Journal of the Academy of Marketing Science Journal of Product Innovation Management
Sub-field 5: Supplier involvement • Hult and Swan (2003) • Rao and Holt (2005) • Georgiadis and Besiou (2008) • Arundel and Kemp (2009)	Journal of Product Innovation Management International Journal of Operations & Production Management Journal of Cleaner Production Book
Sub-field 6: Market focus • Day and Wensley (1988) • Kohli and Jaworski (1990) • Pujari (2006) • Piercy (2009) • Hermosilla (2010)	Journal of Marketing Journal of Marketing Technovation Book Journal of Cleaner Production

Notes: Legend and Journal count – Journal of Cleaner Production=4; Ecological Economics=3; Book=3; Journal of Product Innovation Management=3; Synthesis Report=2; Journal of Marketing=2; Research Policy=1; Journal of Environmental Economics and Management=1; Environmental and Resource Economics=1; Discussion Paper=1; Journal of Innovation Management=1; International Marketing Review=1; Technovation=1; Journal of the Academy of Marketing Science=1; International Journal of Operations & Production Management=1

Curative technologies repair damages such as contaminated soils, whereas, preventative technologies try to avoid the problem. Eco-innovation most likely used in the firms from green product sourcing, efficient energy use or pollution control (Doran and Ryan, 2012). It leads to further innovation success in the future if innovation capacities of the firm are highly developed. However, it is necessary to build up such capital stock inputs like research and development (R&D) investment and higher education of the employees. Baumol (2002), express the technology as "innovation breeds innovation". In other words, firms that build in technology and invest in R&D induce further innovation.

Environmental Management Systems (EMS) can be represented as environmental organizational innovations. Environmental management systems play an important role in eco-process and eco-product innovations (Horbach et al., 2012;

Figure 1. A parsimonious model of eco-innovation



Khannaet al., 2009). EMS is important because it overcome the incomplete information within a firm especially for the introduction of cost-saving cleaner technologies (Horbach et al., 2012). EMS serves as a tool to detect the lacking information when firms face difficulties to recognize the potential cost savings for eco-innovation, such as material or energy savings.

4.1.3. Cross-Functional Coordination

Cross-functional coordination is defined as an attitudinal approach considering integration as "collaboration" (a mutual process with common understanding and goals) or a behavioural approach describing the intensity of interaction and information sharing between the actors. Cross-functional coordination influences the innovation decision such as knowledge transfer and in net-work (Horbach et al., 2012). In the early stage of developing new products or services, a firm requires a cross-functional team approach to eliminate traditional functional limitations and barriers (Payne and Frow, 2005; Cooper, 1994). However, during development, later stages of test marketing and commercialization, cross-functional coordination increase the market and customer knowledge among all project team members.

Recent new product environment study mentioned the importance of interfaces between marketing and R&D, co-ordination among internal groups, the role of team members and leaders, and multi-disciplinary inputs into the new product project (Pujari, 2006). Clercq, Thongpapanl and Dimov (2011) argued that effective knowledge exchange between functional departments and the associated capability to convert intra-organizational collaboration into product innovativeness are depends on two dimensions of organizations' structural context which are shared responsibility and decision autonomy. The lack of a cross-functional team, without a clear leader, and empowered and dedicated team members, might be the reason for a project delays, errors in product design, and miscues in the project (Cooper, 1994).

4.1.4. Supplier Involvement

Besides, it is also significant to take suppliers into account when firms started to involve eco-innovation activities. Previous researches highlight that purchased materials and components from suppliers heavily influence the quality, competitiveness, lead times, development cycles, product design, cost dependency, development risks and market availability of manufacturer's products (Pujari, 2006; Hult and Swan, 2003). For example, following the Oslo Manual, a firm can innovate (eco-innovate) by purchasing cleaner production technology from a supplier and implementing the technology into its production line (Arundel and Kemp, 2009). Firms may benefit from the suppliers involvement in new product development. For instance, firms increase quality with fewer defects, reduce time to market, minimize the development costs as well as supplier-originated innovation.

A company which give emphasis to environmental concerns with their suppliers and customers has a sustainable management approach in order to achieve environmental and productivity gains (Georgiadis and Besiou, 2008). To gain competitiveness, it is necessity for firms to monitor, assessment and audit of suppliers in the value chain management continuously (Rao and Holt, 2005). To manufacture a same product, each supplier will have different levels of sustainability and it is depending on their location and manufacturing practices (Olson et al., 2011).

4.1.5. Market Focus

Lastly, previous scholars had commented that the market focus or market orientation is one of the main drivers for firms success in a new product innovation such as eco-innovation (Piercy, 2009; Kohli and Jaworski, 1990). Market orientation helps a firm to develop better understanding of its target market and their needs and wants for successful new products (Day and Wensley, 1988). Hence, it is essential to establish specific target markets for greener products and assessing market needs (Hermosilla et al., 2010). Besides, consumer perception on the innovation and the characteristics helps the firm to determine market needs and the demand of eco-innovations products (Doran and Ryan, 2012). Piercy (2009) also highlights the main keys elements of market orientation are including the market definition, market segmentation and product differentiation; construct marketing mix; and develop strategy design and execution for the entire market.

Product markets which are close to final customers are crucial when come to eco-innovation (Khanna et al., 2009). It is because customers are the person who willing to spend or pay premiums for environmentally friendly products. At the same time, eco-innovations allow firms to produce better quality of environmental friendly products and gain competitive advantage from their competitors. For example, a study found that consumers in the UK, the USA, Italy, Japan, Canada, Spain and Germany are willing to pay five to ten percent for environmental friendly goods. Hermosilla et al. (2010) emphasizes that user behaviour plays an important role in the application of eco-innovations and their resulting impacts on society. Therefore, market focus becomes one of the factors influencing the market performance of greener products (Pujari, 2006). In the last section, we derive some conclusions based on analysis of existing previous studies.

5. DISCUSSION AND CONCLUSION

This study attains the objective through a simpler parsimonious model. Previous literature has shown that different factors such as regulation, technology, cross-functional coordination, supplier involvement and market focus influence the firm's decision to apply eco-innovation. Yet, the existing empirical literature only analysis the determinants of eco-innovation in general, in turn, it is lack of more detailed empirical explanation. This study builds up a better understanding which enhances the adoption of eco-innovation. However, to achieve sustainability and survive in the long term, a firm need to be competitive in market such as incorporating eco-innovation into the firm's business model. Besides, types of policy intervention or market expectations will vary based on different areas of environmental impact such as pollution of water, air or soil, recycling or climate change, or energy and material used. As a result, different environmental fields may lead the market success play a different role.

Therefore, future studies need to test empirically a parsimonious model of eco-innovation in order to contribute the concept and strengthen theory of eco-innovation. Some future directions may need to be considered in eco-innovation study:

1. Investigate the impact of eco-innovation on the outcome of sustainable business performance which including environmental performance, economic performance and social performance. In return, there is always argument about the sustainable performance of business of the companies is overlooking to the challenges and opportunities surfaced by sustainability issues. Therefore, to make a business succeed in a sustainable world, Murthy (2012) suggests that business must continuously identify, explore and build those new strategic capabilities.
2. Different impacts of eco-innovations introduced by firms in green technology sector. Green technology is important as it is an advance which including various kinds of methodologies and materials enhancement, from techniques for generating energy to non-toxic cleaning products (KamrudinBakar et al., 2011) and increase the societal push for environmental friendly mechanisms to help reduce negative environmental impacts (Cheng and Shiu, 2012; Rennings, 2000).
3. Study of eco-innovation and service innovation is needed where focus of these in different directions. Eco-innovation increases environmental effectiveness (Horbach et al., 2012) and create win-win situation characterized by both economic and environmental benefits (Jaffe, Newell and Stavins, 2003). By practising service innovation, a company could add the value of service to customers. The best way to implement service innovation is that firm seeks for any possibilities continuously by learning and understanding their business environment (Fernando, 2013). Therefore, there is a room for future study to explore the interaction between eco-innovation and service innovation. If eco-innovation was managed properly, it would make the company have a platform for service innovation capability.

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KEY TERMS AND DEFINITIONS

Environmental Stewardship: Human responsible consumption, protection of the natural environment or corrective activities that could be achieved through conservation efforts and sustainable practices.

Green Operations: Day-to-day business activity which focus on cost-efficient and productivity to make less impact and support sustainability.

Operations Strategy: The managerial activities which ranged from plan, organizing, actuating and controlling day-to-day business operation, production, transporting, warehousing, distributing with the best resources allocation to satisfy the end users and stakeholders in organization.

Sustainability: A key for any corporation to develop a sustained business operation as it suggests that businesses should grow and meet the needs of the present without compromising the ability of the future generations to meet their own needs.

Sustainable Business Performance: Is achieved when green supply chain management practices were embedded in the business model of an organization.

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