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Mrinmoy Majumder

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Mrinmoy Majumder
National Institute of Technology Agartala
Agartala
India

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Preface

The availability of water is under stress due to increase in population density, number of industries, degradation in quality of water and impact of climate change. The uneven distribution of water within different regions of the world is also attributed to be one of the reasons why water is scarce in many countries, whereas in some other countries the resource is so abundant that it is wasted for luxury. Moreover, the available resources of water is not optimally utilized. The method of water allocation followed in many countries has no specific rules or regulations. Allocation is carried out based on demand from consumers.

In most countries distribution of water happens in a uniform manner without consideration of demand, socio-economic capacity or any other attributes of a consumer. Thus the consumer with a low demand is allocated the same amount of water as a high-demand consumer. In this manner, a lot of water is either wasted or remains non-utilized. Also, there are no specific methods to monitor and track the availability of water. There are some indicators developed in this aspect but they have many limitations.

For instance, some do not consider the quality parameters. In some other indicators the temporal variation of the input parameters are not considered. However, most of the index has a common drawback, which is the allocation of importance to influence availability of water uniformly among all the parameters. Hence, the importance of rainfall as the major source of water availability is the same as the role of surface water abstractions. There is no provision to distinguish the parameters based on their influence on availability of water.

In the present study we tried to develop an indicator to estimate the status of water availability of any location considering the importance of each parameter over the other in controlling the availability of the resource. In this regard a hybrid MCDM method was utilized where fuzzy logic decision-making and analytical hierarchy process were merged to estimate the priority value or weights of importance of each of the selected input parameters; although the final value of the index was predicted with the help of artificial neural networks. The temporal variation of the input parameter is utilized. Quality parameter is also included, and each parameter is weighted as per its importance in determination of availability of water resources in the region.

Sensitivity analysis of the index was performed. The same index was used for estimation of the severity of water scarcity in three different locations with three different levels of urban population. The value of the index was predicted based on the impact of climate change on the input parameters based on scenarios A2 and B2 of IPCC under three different time slabs.

The results show that for scenario A2 the water shortage will be higher in the location having larger population density. In A2 the impact will be most severe in the last time slab, whereas for B2 the severity will be felt only in the middle time slab.

With respect to priority value, the Frequency of Troughs in Annual Hyetograph (P) and Percentage Impervious Area (A) was found to be the higher and lower important parameters, respectively, among the selected eight input factors.

Chapter 1 gives a brief introduction to the study. It introduces to the reader the need and importance of the present investigation and describes the methodology adopted and the tools and concepts utilized.

Chapter 2 gives an overview of multi-criteria decision-making. The working procedure, two examples and their applications to solve real-life problems in water resources are discussed.

Chapter 3 describes the artificial neural network and its working principle to solve complex nonlinear problems by learning the same from the available data.

Chapter 4 explains the causes and impacts of climate change and introduces the concept of climate models, Global Climate Model (GCM) and Regional Climate Model (RCM). The study utilizes the output of an RCM, PRECIS model for generating the future climate data. PRECIS is also discussed in this chapter.

Chapter 5 depicts the detailed methodology adopted to achieve the objectives of the study, while Chap. 6 explains the results and proposes the necessary reasons for the outcome. Chapter 7 draws the conclusions with a brief summary of the study, its drawbacks and the possible future scope.

Contents

Chapter 1
Introduction

Abstract The present study tried to achieve three objectives. The first objective is to develop an indicator to represent the real situation of water availability in different locations as a function of urbanization, climate and water quality. The indicator will consider the temporal variation of its input parameters and water quality parameters. The second objective was to identify the priority values of the input parameters to differentiate the input variables with respect to its sensitivity to the amount of consumable fresh water. The last aim of the investigation was to find the impact of urbanization on water availability under different climatic scenarios. To achieve all three objectives, Multi Criteria Decision Making (MCDM) and Artificial Neural Network (ANN) was used to develop the index after the input parameters were identified with the help of literature, expert and stakeholders survey. ANN was selected for its predictive ability under non-linear and complex situations. A new MCDM method, Ensemble Analytical Hierarchy Process and Fuzzy Logic was utilized for decision making about the importance of selected parameters and determination of the priority values. Three study areas having three different densities of urban population was selected. Climate change scenarios A2 and B2 as proposed by Inter-Governmental Panel on Climate Change (IPCC) was considered to represent the climatic situations where the values of the climatic parameters was predicted by Climate Models. For each scenario, the index value was estimated for three different time slabs (2010–2030, 2031–2070 and 2071–2100).

Keywords Decision making in water resources · Multi criteria decision making · Artificial neural networks · Climate change · Urbanization impact · Water shortage indicator

1.1 Definition of Water Shortage

According to the Ecology Dictionary (ED 2014), Water shortage is defined as "The situation within all or part of the District when insufficient water is available to meet the present and anticipated needs of the permit system, or when conditions are such

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as to require temporary reduction in total use within a particular area to protect water resources from serious harm". In general terms, water shortage is defined as the lack of sufficient available water resources to meet the demands of water usage within a region. According to RWL (Paulson 2013), "Water shortage can be defined as a condition in which people lack sufficient water or else do not have access to safe water supplies".

Water shortage is also referred as water scarcity. In conclusion, *the definition of water shortage or scarcity can be defined as lack of water available both in quantity and quality for the use of the local population of a region.*

1.2 Causes

The main causes of water shortage may be attributed to:

1. Urbanization
2. Water Pollution
3. Climate Change
4. Mismanagement of Available Water Resources

1.2.1 Urbanization

In the urbanization process rural population metamorphose to a part of urban population.

In order to carry on the sustenance of the excess population addition of more roads, houses, and commercial and industrial buildings is necessary.

The additional development has its own impact on the urban ecology and ecosystems. The addition of road, buildings and industry step-up the amount of impervious area in a region. This decrease the accessibility of water as amount of surface runoff also increases due to the reduction of infilterable area.

In addition to this, overgrowth in density of population and change in land use and land cover is two other impact of urbanization. Both of this changes will increase stress on natural resources of the region and will also change the nature of stakeholders.

The accumulative impact of all the above will be on water availability.

As population increases so will be the demand for water. One of the ill effects of increasing concentration of industries is the toxic discharges from them which will pollute the surface water resources.

Again to sustain the livelihood and satisfy the demand of the population the conversion of forest land to agriculture and/or industrial lands will take place. To provide shelters or space for the commercial enterprises vast area of forest cover will also be uprooted.

Thus, the amount of water flowing out of the region will increase due to the reduction of infiltration capacity of the region. Thus availability of water will reduce both in quality and quantity as an impact of urbanization.

The urbanization impacts on water availability can be grouped into following four classes.

1. Population Overgrowth
2. Landuse Change
3. Stress on available Resources
4. Change in Nature of Stakeholders

1.2.1.1 Population Overgrowth

The water balance equation as proposed by United Nation For Climate Change clearly indicates that the volumes of water that can be stored in the basin depend on climatic as well as geo-physical properties of the catchment. The available volume of water in a catchment is a direct function of climatic factors like Precipitation and inverse function of Evapo-transpiration. The geophysical properties along with the soil characteristics influences the amount of water that can be infiltrated, flows out of the catchment as surface runoff or get retained due to the depressions available in the basin.

The amount of water that can be consumed for different purposes like domestic, agricultural and industrial uses depends not only in the volumes of water available but also on the quality of water. The rate of population growth is found to be 80 million per year. As a consequence, the demand for both water and energy has increased. As energy potential also depend upon the volume of water available, demand for water has aggravated rapidly.

The abjuration of freshwater worldwide has tripled in the last 50 years. The postulation for freshwater has inflated by 64 billion cubic meters a year. The industrial sector was found to engross 70 % of the World's available freshwater followed by agriculture sector (20 %) and 10 % is consumed by the domestic sector. In industrialized nations, however, industries consume more than half of the water available for human utilisation. Belgium, for instance, uses 80 % of the water for industry.

According to the interpretations of Water.org, which is an international organization working to solve the global water crisis:

- Nearly 780 million people in the world lack access to clean water.
- Each year 60 million people is added to different cities of the World.
- Within the following 40 years, there will be 2–3 billion people living in the World. As a result expected increase of food demand will be about 70 % by 2050.
- About half of the global population lives in metropolis areas, and the concentration of urban population is accretive each day.

Although, urban areas are superior than rural areas, but due to the burgeoning growth in urban settlements, giving provision to the rising demand is becoming problematic (UNICEF 2010).

1.2.1.2 Landuse Change

"Land use is characterised by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it" (FAO 2014a, b). Land use refers to the human utilisation of the land (Modi 2013).

Land can be utilized for residential, agricultural or industrial purposes. Land can be utilized to make roads, water bodies and other supports to provide obligatory requirements to continue livelihood.

Whenever a land is transformed from the earlier use, it modifies among others, the water quality and hydrologic regime of the region (Kiersch 2002).

According to Kiersch (2002), the "impacts of land use on water resources depend on a host of natural and socio-economic factors". "Natural factors" include climate, geography and soil composition. "Socio-economic factors" consist the economic susceptibility and consciousness of a farmer and developmental works which have absolute or allusive impact on land use change.

The land use change can alter the hydrologic regime and quality of water.

Impact on Hydrologic Regime

Land use alteration can cause the overall water availability or the mean annual runoff, and the year-around distribution of water availability by influencing the following parameters. Each of the following parameters has its own impact on water availability.

1. Mean Surface Runoff
2. Peak Flow
3. Dry Season flow
4. Groundwater Recharge

Mean Surface Runoff

The impact of land use on the mean runoff is a function of numerous factors, the most important of them are:

- the water regime of the flora cover in terms of evapotranspiration (ET)
- the cognition of the soil to hold water (infiltration capacity)
- the capacity of the plant cover to intercept moisture. An exclusion to this rule are cloud forests, which can tap more moisture than consumption by ET, and very old forests, which, depending on the species, may adsorb less water than the new vegetations, that substantiate itself after clear-cutting (Calder 1998).

The increment in discharge or surface runoff diminishes over time, with formation of new plant cover, but time scales can change greatly.

In wet and warm areas, the impact of clear-cutting is shorter lived than in less humid areas, due to fast maturation of floral population (Falkenmark and Chapman 1989).

Increasing water yield from changing plant canopy does not, inevitably increase water availability downstream, the runoff may lessen because of water intake by riverside vegetation or by channel infiltration (Brooks et al. 1991).

Peak Flow

Peak flows can increase as a consequence of a change in land use if the infiltration capacity of the soil is attenuated, for example, through soil compaction or erosion, or due to increase of drainage capability. Peak flow may aggrevate after cutting of trees (Bruijnzeel 1990).

Relative increases in storm flow after tree removal are smallest for large events and largest for small events. As the volume of precipitation increases, impact on storm flow of soil and plant cover diminishes (Bruijnzeel 1990).

A gain of peak flows may also result from the building of roads and infrastructure.

Studies in the north-western USA have shown that the construction of forest roads can intensify peak runoff from forested areas significantly. Integration of smaller plots to large fields can lead to higher runoff rates, due to drainage systems and asphalt access roads (Falkenmark and Chapin 1989).

Conversely, peak flows may decrease as a result of an increased soil infiltration capacity.

Dry Season Flow

The impact of land use change on dry-season flow depends on the following competing processes:

- changes in ET
- changes in infiltration capacity.
- The net impact is highly location specific (Calder 1998).

In tropical areas, afforestation can lead to decreased dry-season flows due to increased evapotranspiration.

The most of the literary study evidenced in rainfall-dominated regimes suggests that uprootal of forest cover or conversion from water filic to water phobic plants may increases dry season flows (Brooks et al. 1991).

The dry-season flows from deforested land may decrease if the soil infiltration capacity is reduced for utilization of heavy machinery for agricultural practices (Bruijnzeel 1990).

Lean flow developed from enlarged arid periods or droughts may not change substantially due to the changes in vegetative cover (Brooks et al. 1991).

Groundwater Recharge

The groundwater recharge may be increased or decreased as a result of changing land use practices. The major factors are the ET of the vegetative cover and the infiltration capacity of the soil. Groundwater recharge is influenced by dry-season flows as during that time groundwater feeds the river discharge.

The water table may rise as a result of decreased evapotranspiration as for example:

> Recharge may increase due to logging or conversion of forest to grassland for grazing.
> Recharge may also increase due to an increased infiltration rate, e.g. through afforestation of degraded areas (Tejwani 1993). In contrast, the water table may fall as a result of decreased soil infiltration, e.g. through non-conservation farming techniques and compaction (Tejwani 1993).

Impact on Water Quality

The landuse change can influence the water quality in the following manner:

- Erosion and Sediment Load
- Nutrients and organic matter
- Pathogens
- Pesticides and other persistent organic pollutants
- Salinity
- Heavy metals
- Changes in thermal regime

Erosion and Sediment Load Properties

Amount and type of forest are factors which can control soil erosion. The understorey vegetation and litter, and the stabilization effect of the root network protects the soil cover and prevents from being eroded. Afforestation has no effect on soil erosion. Splash erosion may increase substantially when litter is cleared from the forest floor (Bruijnzeel 1990). Deforestation may aggrevate erosion. In Malaysia, streams from logged areas carry 8–17 times more sediment load than before logging (Falkenmark and Chapman 1989). Sediment can act both as a physical and a chemical pollutant.

Physical contamination by sediments mainly includes:

- increase in turbidity (limited penetration of sunlight)
- sedimentation (loss of downstream reservoir capacity, destruction of coral reefs, loss of spawning grounds for certain fish).

Chemical pollution of sediment includes:

- adsorbed metals and phosphorous
- contamination of hydrophobic organic chemicals (FAO 1996).

Nutrients and Organic Matter

A land use change can deviate the nutrient concentration of surface and groundwater specially the concentration of nitrogen (N) and phosphorus (P). The reason can be attributed to:

- Deforestation
- Agricultural Activities
- Freshwater Aquaculture

Due to Deforestation
Deforestation can lead to high nitrate (NO3) concentrations in water due to decomposition of plant material and a reduced nutrient uptake by the vegetation. The concentration of Nitrate in runoff from deforested catchments can be 50 times higher than in a forested control catchment over several years (Falkenmark and Chapman 1989; Brooks et al. 1991).

Due to Agricultural Activities
Agricultural activities can lead to an increased influx of nitrogen into water bodies as a consequence of:

- fertiliser application
- manure from livestock production
- sludge from municipal sewage treatment plants
- aeration of the soil.

Phosphate contaminated sediments can produce a nutrient pool in the bottom of eutrophic lakes, which can be extinguished into the water under anaerobic conditions. This makes it difficult to control eutrophication in the short term through limitation of P inflow. Eutrophication can be mitigated by dredging sediment or oxidising the hypolimnion, but these options are expensive (FAO 1996).

Due to Freshwater Aquaculture
Freshwater aquaculture can also contaminate surface water through:

- waste feed that is not consumed by the fish
- the fish's faecal production

Pathogens
The density of pathogenic bacteria in surface waters may increase as a result of riparian grazing activities or waste influx from livestock production. A reduction of stream flow as a consequence of upstream diversion for irrigation, may lead to ponding in riverbeds, which in turn may provide breeding grounds for vectors of waterborne diseases, such as malaria. The low flow of the rivers in estuaries can spread vectors breeding in brackish water.

Pesticides and other persistent organic pollutants
As pesticide compounds are toxic and persistent mixing of such compounds into surface and groundwater sources can be fatal. Pesticide can contaminate groundwater based on their chemical's persistence and mobility, as well as the soil structure.

In humans and animals, pesticides can have both acute and chronic toxic effects.

Pesticide contamination occurs due to their use in agriculture, forestry and aquaculture. "Furthermore, unsafe stockpiling and dumping of old and obsolete pesticides can cause severe ground and surface water contamination" (FAO 1996).

Salinity
Agricultural activities can lead to increased salinity of surface and groundwater due to the evaporation and the leaching of salts from soils.

A high application rate of potassium chloride fertiliser can lead to an increased leaching of chloride into groundwater.

In coastal areas, groundwater extraction for irrigation, domestic and industrial purposes can induce the intrusion of seawater into the aquifer, and consequently a salinization of the groundwater resources will take place.

A decrease in river discharge due to upstream new reservoirs, can also lead to an inland intrusion of brackish water in the estuarine zone.

Heavy metals
The release of organic waste in the runoff can create a direct pathway for heavy metals to contaminate the surface water or groundwater sources. Pig manure contains high concentrations of copper (FAO 1996). When such wastes are mixed with the streams it becomes contaminated. Many local inhabitants earn their livelihood by culturing pigs. When a certain land is converted as a residential place for such kind of people then chance of contamination gets increased.

The land use change also impacts the mobility of heavy metals. The heavy metals can be transferred by erosive processes, acidification of soil or excessive application of water on soil. The increase in application of water from ground water or surface water sources can increase the soil solubility and which can imbibe mixing of heavy metals in soil particles.

Changes in thermal regime
In mini channel flow, uprootal of riparian vegetation can imbibe rise in the temperature of the water (thermal pollution). Also, rise in temperature can be observed in streams receiving agricultural runoff. As temperature rise is inversely proportional to oxygen solubility of streams, increase in temperature will always degrades the self-cleaning ability and biological activity of the rivers.

1.2.1.3 Stress on Available Resources

As the century begins, natural resources are under increasing pressure, threatening public health and development. Water shortages, soil exhaustion, loss of forests, air and water pollution, and degradation of coastlines afflict many areas. As the world's population grows, improving living standards without destroying the environment is a global challenge.

Most developed economies currently consume resources much faster than they can regenerate. Most developing countries with rapid population growth face the urgent need to improve living standards. As the century begins, natural resources are under increasing pressure, threatening public health and development. Water shortages, soil exhaustion, loss of forests, air and water pollution, and degradation of coastlines afflict many areas. As the world's population grows, improving living standards without destroying the environment is a global challenge.

Most developed economies currently consume resources much faster than they can regenerate. Most developing countries with rapid population growth face the urgent need to improve living standards (Hinrichsen and Robey 2000).

As the population and their requirement to sustain their livelihood is increasing at a steady rate the stress on natural resources like land, water and energy is also increasing steadily.

> When population growth is combined with extortionate consumption of natural resources, problems amplify. At present, 20 percent of the world's people in the highest-income countries account for 86 percent of the full private consumption expenditures, while the poorest 20 percent consume only 1.3 percent. The anisometric distribution of wealth and resources leads to unmindful waste and excess in the wealthy nations, and suffering in the resource-starved regions. (CWAC 2014)

This inequality can be seen in the consumption of water in America when compared to the other parts of the world. The world's population is continuously growing, so the demand of water is also, but we have a limited water supply. It is important that industrialized nations realize the demand for water globally and therefore practice conserving the current water supply.

When the population increases so does the consumption of water; it is estimated that by 2025 2–3 billion people will be living in countries experiencing conditions that are water-stressed. In the 20th century the world's population has tripled, but the consumption of the water resources has grown sixfold. It is also estimated that in the next 50 years the world's population will again grow 40–50 % and if we continuously use the amount of water that we are currently using the water supply will significantly diminish.

An increase to the population would also bring industrialization and urbanization which causes environmental problems which directly affects the quality of the water supply and creates conditions of water shortage. Presently we are globally enduring 1.1 billion people not having access to safe drinking water and 2.6 billion people not having sufficient sanitation supplies leading to the loss of life of 3900 children every day from waterborne diseases. Even in America the reality that is harsh of population increase and its affects on our water supply. About 218 million American citizens live at least 10 miles from a impure water source, giving the estimate of 40 % of water in America is unsafe for fishing, swimming, or aquatic life.

Scarce Water

Around 1.2 billion people, or almost one-fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage. Depending on future rates of population growth, between 2.6 and 3.1 billion people may be living in either water-scarce or water-stressed conditions by 2025.

Scarce Cropland

Increasing soil and land degradation is damaging harvest and crop land all through the world, with more than 10 million hectares of effective crop land so severely debased they have to be deserted each year. In addition, salinization is loss that is causing of

10 million hectares per year. Due to the fact of the deficits, approximately 30 % of the world's cropland has been discontinued during the past 50 years. The number of people surviving in countries where cultivated land is significantly scarce is projected to increase in between 600 million and 986 million around 2025.

Fisheries
Most of the world's ocean fisheries are already being fished to their maximum capacities or are in decline. Our appetite for fish is exceeding the ocean's ecological limits with devastating impacts on marine ecosystems.

Forests
According to the U.N. Food and Agriculture Organization Global Forest Resources Assessment 2005, the net loss in forest area at the global level during the 1990s was an estimated 94 million hectare—an area larger than Venezuela and equivalent to 2.4 % of the world's total forests. Throughout the 1990s many countries with high rates of deforestation also had rapid population growth. In 1995, close to 1.7 billion people lived in 40 forest-scarce countries, those with less than one-tenth of a hectare of forest per capita. By 2025, 4.6 billion people will live in forest-scarce countries. By then watersheds in China, Nepal, Thailand, and Vietnam are projected to be critically degraded as a result of the loss of forest cover.

1.2.1.4 Change in Nature of Stakeholders

When transformation of land use takes place, the character of the people also evolves. For example people living encompassing an farming zone will be imposed to change their livelihood and income possibilities when the land will be translated into industrial land. The same agriculture labours will become industrial workforce. It is observed in all parts of the world that people adjust and adapts to change inland type so that they can sustain the new form to their livelihood of opportunities.

Land-cover change has been identified as one of the most important drivers of change in ecosystems and their services. However, information on the consequences of land cover change for ecosystem services and human well-being at local scales is largely absent.

Where information does exist, the traditional methods used to collate and communicate this information represent a significant obstacle to sustainable ecosystem management. Embedding science in a social process and solving problems together with stakeholders are necessary elements in ensuring that new knowledge results in desired actions, behavior changes, and decisions.

An effort has been made to deal with this identified information gap, as well as the way information is gathered, by quantifying the localized consequences of land-cover change for ecosystem services in the Little Karoo region, a semiarid biodiversity hotspot in South Africa. The entire region was mapped and quantified based on the potential supply of, and changes in, five ecosystem services: generation of forage, carbon retention, erosion management, water flow control, and tourism. The outcomes exhibited considerable (20–50 %) declines throughout ecosystem services as a result of land-cover change in the Little Karoo (Reyers et al. 2009).

1.2.2 Water Pollution

The effects of water pollution are varied and depend on what chemicals are dumped and in which locations. Many water bodies near urban areas (cities and towns) are highly polluted. This is the result of both garbage dumped by individuals and dangerous chemicals legally or illegally dumped by manufacturing industries, health centers, schools and market places. The causes of water pollution can be contributed by:

1. Water and Energy Demand
2. Increase in Concentration of Industries
3. Increase in Agriculture Activities
4. Increase in Amount of Urban Domestic Waste
5. Increase in Power Plants

1.2.2.1 Water and Energy Demand

Fossil fuels like coal and oil when burnt produce substantial amount of ash in the atmosphere. The particles which contain toxic chemicals when mixed with water vapor result in acid rain. Also, carbon dioxide is released from burning of fossil fuels which result in global warming.

According to the US Energy Information Administration (EIA), fossil fuels meet around 82 % of U.S. energy demand.

Fossil fuels make modern life possible. These huge sources of energy work to generate steam, electricity and power transportation systems. They make the manufacturing of tens of thousands of commercial goods possible. And although fossil fuels have become synonymous with modern industrial society, their potential to solve some of the challenges of everyday existence has been understood throughout history.

Scattered records of the use of coal date to at least 1100 BC. By the Middle Ages, small mining operations began to spread in Europe, where coal was used for forges, smithies, lime-burners, and breweries. The invention of fire bricks in the 1400s made chimneys cheap to build and helped create a home heating market for coal. Coal was firmly established as a domestic fuel in much of Europe by the 1570s, and represented the major heating source for buildings, especially in cities located far from easy access to less energy-dense biomass forms.

Despite concerted global efforts to reduce carbon emissions through the expansion of clean and renewable energy resources, fossil fuels continued to dominate the global energy sector in 2012, according to new figures released yesterday by the Worldwatch Institute.

Coal, natural gas and oil accounted for 87 % of the world's primary energy consumption last year, the group reported in a new "Vital Signs Online" report.

"The relative weight of these energy sources keeps shifting, although only slightly," states the report by researchers Milena Gonzalez and Matt Lucky, members of the Worldwatch Institute's climate and energy team.

While the U.S. boom in shale gas helped push the fossil fuel's share of total global energy consumption from 23.8 to 23.9 %, coal also increased its share, from 29.7 to 29.9 %, as demand for coal-fired electricity remained strong across much of the developing world, including China and India, and parts of Europe.

As such, coal is expected to surpass oil as the most consumed primary energy source in the world, the report said. In 2012, China alone accounted for more than half the world's total coal consumption, mostly for electric power generation.

But natural gas is also seeing significant gains, both in the United States and in countries like Japan, which are shifting their energy portfolios away from nuclear power. "With increasing shale gas fracking and many countries' interest in displacing coal generation with natural gas due to the lower greenhouse gas emissions, natural gas use seems well poised to grow," the report states (Cusick 2013).

1.2.2.2 Increase in Concentration of Industries

Industries produce huge amount of waste which contains toxic chemicals and pollutants which can cause air pollution and damage to us and our environment. They contain pollutants such as lead, mercury, sulfur, asbestos, nitrates and many other harmful chemicals. Many industries do not have proper waste management system and drain the waste in the fresh water which goes into rivers, canals and later into sea. The toxic chemicals have the capability to change the color of water, increase the amount of minerals, also known as Eutrophication, change the temperature of water and pose serious hazard to water organisms.

Mining is the process of crushing the rock and extracting coal and other minerals from underground. These elements when extracted in the raw form contain harmful chemicals and can increase the amount of toxic elements when mixed up with water which may result in health problems. Mining activities emit several metal waste and sulphides from the rocks and is harmful for the water.

Allthough World GDP is has decreased from 2010 to 2013 (from 4.1 to 2.2) (World Bank 2014). But the global volume of international virtual water flows in relation to trade in agricultural and industrial products averaged 2320 billion m^3 per year during the period 1996–2005 (Mekonnen and Hoekstra 2011). The major gross virtual water exporters were the USA, China, India, Brazil, Argentina, Canada, Australia, Indonesia, France and Germany and the major gross virtual water importers were the USA, Japan, Germany, China, Italy, Mexico, France, the UK and the Netherlands. The biggest net exporters of virtual water are found in North and South America (the US, Canada, Brazil and Argentina), Southern Asia (India, Pakistan, Indonesia, Thailand) and Australia. The biggest net virtual water importers are North Africa and the Middle East, Mexico, Europe, Japan and South Korea.

For water-scarce countries it can sometimes be attractive to import virtual water (through import of water-intensive products), thus relieving the pressure on the domestic water resources. This happens for example in Mediterranean countries, the Middle East and Mexico. Also Northern European countries import a lot of water in virtual form (more than they export), but this is not driven by water scarcity. International trade patterns can only be understood from a multitude of factors; water scarcity is merely one of them.

Virtual Water

Virtual water is defined as the total volume of water needed to produce and process a commodity or service.

The global footprint of water resources is 1385 m^3/year per capita (Mekonnen and Hoekstra 2011).

Water Footprint

Where the Water Footprint is defined as an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer.

The water footprint of an individual, community or business is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business. Water use is measured in terms of water volumes consumed (evaporated or incorporated into a product) and/or polluted per unit of time.

A water footprint can be calculated for a particular product, for any well-defined group of consumers (for example, an individual, family, village, city, province, state or nation) or producers (for example, a public organization, private enterprise or economic sector).

The water footprint is a geographically explicit indicator, showing not only volumes of water use and pollution, but also the locations like:

1. India
2. USA
3. Germany

India

The water footprint of Indian consumption was 987 billion m^3/year in the period 1997–2001, which means 980 m^3/year per capita (Hoekstra and Chapagain 2008). Nearly this entire footprint was within the country. Only 2 % of the water footprint of Indian consumers lies outside the country.

Considerations about the need to augment domestic food production to fulfill the needs of a large and rapidly growing population has encouraged the Government of India to recommend an estimated US$ 120 billion National River Linking Programme envisaging to grid 37 Himalayan and Peninsular rivers. This enormous south Asian water grid will annually handle 178 billion m^3/year of inter-basin water exchange; have water transported through 12,500 km of new canals; generate 34 GW of hydro-power; add 35 million ha to India's irrigated areas and generate inland navigation benefits. Alternatives suggested to this grand project include the use of inter-state virtual water trade instead of physical water transfers to tackle the high spatial variation in water availability across the country.

The existing pattern of inter-state virtual water trade is exacerbating scarcities in already water scarce states, with virtual water flows moving from water scarce to water rich regions and running in the opposite direction to the proposed physical transfers (Kampman et al. 2008; Verma et al. 2008, 2009). Rather than being dictated by water endowments, virtual water flows are influenced by many other factors such as per capita availability of arable land and more importantly by biases in food and agriculture policies of the Government of India as indicated by the Food Corporation of India's procurement patterns. In order to have a comprehensive understanding of virtual water trade, non-water factors of production need to be taken into consideration.

United States of America
The Average water footprint of United States of America is 2842 m^3/year per capita and the part of footprint falling outside of the country is found to be 20.2 %.

Germany
In the past years, the water use in German households as well as in the industrial sector has declined constantly. This trend is very welcome and has to be encouraged in the future. But this amount of water only represents a small portion of the total water the Germans consume on a daily basis. A considerably higher portion is hidden in the food, clothes and other products that citizens use or consume in everyday life. Since many of the products consumed come from abroad, Germany has a significant external water footprint.

The total water footprint of German consumers is 159.5 cubic kilometres of water per year. With a population of currently 82.2 million, each citizen consumes 5288 l of water each day, and only a small portion of it for drinking, cooking or other household activities.

The biggest amount of this water is hidden in the food or products that are consumed each day. About half of the German agricultural water footprint is made up by imported products or food. That means that by importing those goods, water in virtual form was also imported from the producing countries. Germany has thereby left its water footprint in those countries. The imported goods with the highest water footprint are—in descending order—coffee, cocoa, oilseeds, cotton, pork, soybeans, beef, milk, nuts and sunflowers.

The biggest water footprint of Germany is left in Brazil, Ivory Coast, France, the Netherlands, the USA, Indonesia, in Ghana, India, Turkey and Denmark respectively, also in descending order (Sonnenberg et al. 2009).

By observing the status represented by Water Footprint the increased density of industries in these countries can be assumed all though recent GDP of all the countries has decreased.

1.2.2.3 Increase in Agriculture Activities

According to FAO, the percentage use of water for Agriculture, Industries and domestic purposes is respectively 70, 19, 11 % (FAO 2014c).

Agriculture is the world's largest industry. It employs more than one billion people and generates over $1.3 trillion dollars worth of food annually. Pasture and cropland occupy around 50 % of the Earth's habitable land and provide habitat and food for a multitude of species.

Agriculture, and especially irrigated agriculture, is the sector with by far the largest consumptive water use and water withdrawal.

When agricultural operations are sustainably managed, they can preserve and restore critical habitats, help protect watersheds, and improve soil health and water quality. But unsustainable practices have serious impacts on people and the environment.

The need for sustainable resource management is increasingly urgent. Demand for agricultural commodities is rising rapidly as the world's population grows. Agriculture's deep connections to the world economy, human societies and biodiversity make it one of the most important frontiers for conservation around the globe.

The priority agriculture commodity was found to be Beef, Soy, Palm Oil, Sugarcane, Dairy and Cotton (WWF 2014).

Beef

Beef is raised in many of the most sensitive environmental areas around the world. Most of the world's beef is produced in Australia, Brazil, Southern Africa and the United States. Unlike many other agricultural commodities, cattle have significant impacts on a wide range of ecosystems.

With the United Nations forecasting that global population will exceed 10 billion by the end of the century and income levels rising, demand for beef is increasing and only expected to get higher. It is thus essential to improve the sustainability of beef production globally.

Palm Oil

Grown only in the tropics, the oil palm tree produces high-quality oil used primarily for cooking in developing countries. It is also used in food products, detergents, cosmetics and, to a small extent, biofuel. Palm oil is a small ingredient in the U.S. diet, but more than half of all packaged products Americans consume contain palm oil—it's found in lipstick, soaps, detergents and even ice cream.

Palm oil is a very productive crop. It offers a far greater yield at a lower cost of production than other vegetable oils. Global production of and demand for palm oil is increasing rapidly. Plantations are spreading across Asia, Africa and Latin America. But such expansion comes at the expense of tropical forests—which form critical habitats for many endangered species and a lifeline for some human communities.

Soy

Around the world, there is a surging demand for soy—the "king of beans." Soy is a globally traded commodity produced in both temperate and tropical regions and serves as a key source of protein and vegetable oils. Since the 1950s, global soybean production has increased 15 times over. The United States, Brazil, and Argentina together produce about 80 % of the world's soy. China imports the most soy and is expected to significantly increase its import of the commodity.

Soy is pervasive in our lives. Not only are soybeans made into food products like tofu, soy sauce, and meat substitutes, but we also eat them in the form of soybean oil and soybean meal. Soybean meal is widely used as animal feed, so we humans consume much of it indirectly via our meat and dairy.

Without proper safeguards, the soybean industry is causing widespread deforestation and displacement of small farmers and indigenous peoples around the globe.

Sugarcane

Sugarcane is a water-intensive crop that remains in the soil all year long. As one of the world's thirstiest crops, sugarcane has a significant impact on many environmentally sensitive regions, like the Mekong Delta and the Atlantic Forest. Historic planting of sugarcane around the world has led to significant impacts on biodiversity.

A vast global market for sugarcane derivatives keeps the industry booming. Sugar is prevalent in the modern diet and increasingly a source of biofuels and bioplastics. As prices of petroleum rise, there is a growing market for ethanol from sugarcane.

Managing social and environmental risks is important for sugarcane growers, processors and food companies due to regulatory pressures as well as shareholder and consumer expectations for sustainably produced goods.

Dairy

The dairy industry impacts some of the world's most sensitive environmental areas covering a wide range of ecosystems. As milk is not usually shipped internationally and is instead distributed and consumed in its country of origin, the impact of dairy in a given place is primarily a local issue. Dairy farms are often family-owned and seen as essential for rural employment.

Despite its local focus, dairy is indeed a large, global industry—there are approximately 250 million dairy cows in the world. Production systems and practices vary widely across countries. With demand for dairy rising as the world's population grows, it is essential to improve the sustainability of dairy production globally.

The dairy industry poses a number of challenges to the health of the environment. Methane emitted from cows' digestions process—called enteric fermentation—and their manure is the most critical potential impact of dairy production. Water pollution is another major concern, as manure and nutrients run into waterways. The dairy industry is also responsible for land conversion, particularly in the tropics, to grow the feed required by dairy herds.

Cotton

Cotton is the most widespread profitable non-food crop in the world. Its production provides income for more than 250 million people worldwide and employs almost 7 % of all labor in developing countries. Approximately half of all textiles are made of cotton.

The global reach of cotton is wide, but current cotton production methods are environmentally unsustainable—ultimately undermining the industry's ability to maintain future production.

Bringing cotton production in line with even minimally acceptable environmental standards is a challenging task.

It may take 2700 L to produce the cotton needed to make a single t-shirt.

1.2.2.4 Increase in Amount of Urban Domestic Waste

> Water which is of no further immediate value to the purpose for which it was used or in the pursuit of which it was produced because of its quality, quantity or time of occurrence. However, wastewater from one user can be a potential supply to another user elsewhere. Cooling water is not considered to be wastewater (FAO 2014d).

Wastewater can be contaminated by degradable and non-degradable Volatile Suspended Solid (VSS), Colloids and Sorbable and Non-Sorbable Soluble Organics.

In Vietnam the daily production of sewage sludge amounts to 2000 m^3 per day whereas same for Thailand is found to be 36.5 m^3/day. South Africa produces about 50,00,000–70,00,000 m^3/day of sewage of which 57 % are anaerobically digested sludge. The sewage treatment facility of Ghana is very limited and covers only 4.5 % of total sewage sludge generated (Spinosa 2011).

The Figs. 1.1, 1.2 and 1.3 shows the waste water released from different types of consumers.

1.2.2.5 Increase in Power Plants

In recent years due to the increase in urban population and technological developments demand for energy has raised manifold. That is why to satisfy the demand in recent years there is an increase in density of both coal, natural gas and nuclear power plants. As there is an increase in number of power plants the waste from the plants will also increase and so will be the level of contamination.

Nuclear Waste

Nuclear energy is produced using nuclear fission or fusion. The element that is used in production of nuclear energy is Uranium which is highly toxic chemical. The nuclear waste that is produced by radioactive material needs to be disposed off to prevent any nuclear accident. Nuclear waste can have serious environmental

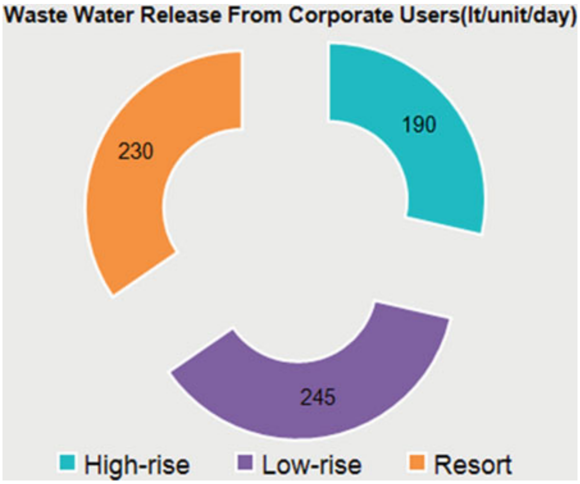

Fig. 1.1 Waste water release from corporate users

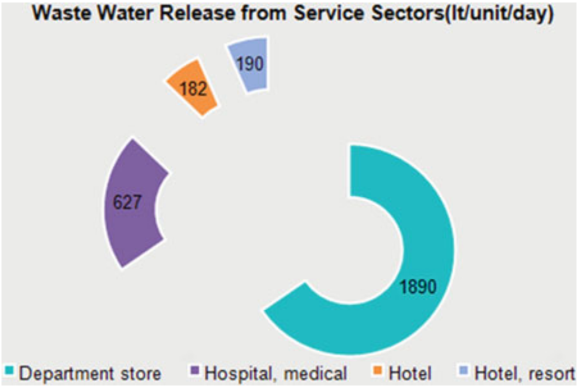

Fig. 1.2 Waste water release from service sectors

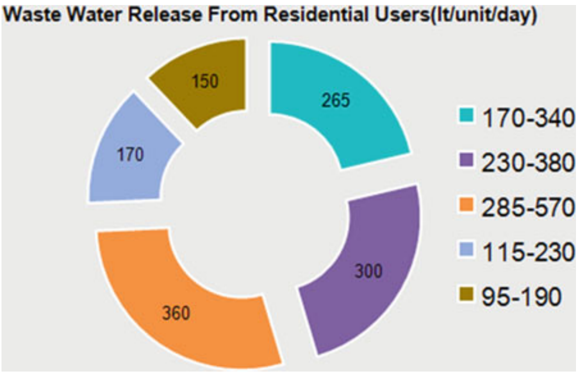

Fig. 1.3 Waste water release from residential users

hazards if not disposed off properly. Few major accidents have already taken place in Russia and Japan.

Coal

Coal is one of the most-water intensive methods of generating electricity. A typical coal plant withdraws enough water to fill an Olympic-sized swimming pool every three and a half minutes. The International Energy Agency says that global water consumption for power generation and fuel production is expected to more than double from 66 billion cubic meters (bcm) in 2010, to 135 bcm by 2035. Coal accounts for 50 % of this growth.

Despite the looming water scarcity crisis, today there are more than 1200 new coal plants proposed around the world. Much of proposed coal expansion is in water stressed regions—regions which already have limited available water for sanitation, health and livelihoods.

China

In China, a coal chemical project in the dry Inner Mongolia region, part of a new mega coal power base, had extracted so much water in 8 years of operation that caused the local water table to drop by up to 100 m, and the local lake to shrink by 62 %. The drastic ecological impacts forced thousands of local residents to become ‘ecological migrants’. This is just the tip of the iceberg—by 2015, China’s current plan of 16 such mega coal power bases will consume 10 billion m^3 of water annually, equivalent to 1/6 of Yellow River annual flow.

India

In India, the energy-water conflict is even starker. According to analysis by HSBC and the World Resources Institute, a staggering 79 % of new energy capacity will be built in areas that are already water scarce or stressed, but coal is still the energy of choice despite the clear water constraint (Greenpeace 2014). A case in point is the plan to build a cluster of 71 coal plants in the highly water stressed Vidarbha region in Central Maharashtra, where there had been over 6000 documented farmer suicides in the last decade due to lack of water for irrigation.

South Africa

In South Africa, the main utility, Eskom, admits that there is no unallocated water available in the catchments that supply its power stations, and argues that, as it is classified as a strategic water user, “water would have to be given up by other users most notably irrigation farmers”. Moreover, Eskom also argues that their coal plants should be exempt from Minimum Emissions Standards because there isn’t enough water to operate the scrubber (Metcalf and Eddy 1991). The excess emissions of sulfur and nitrous oxides and mercury from their coal fleet are projected to cause approximately 20,000 pre-mature deaths.

1.2.3 *Climate Change*

The uncontrolled extraction of natural resources, non-moderated growth in industrial activities, destruction of natural forest and water bodies followed by the rising demand for water and energy from the ever growing population to sustain their livelihood as well as luxury and the recent technological advancements has increased the stress on water resources of most of the countries in the World. The use of fossil fuel has increased many fold compared to the earlier decades and as a result amount of green house gas in the atmosphere has increased. Major impact of climate change is:

1. Rise in Average Temperature
2. Increase in number of Extreme Events
3. Increase in Occurrence of Floods and Droughts
4. Early Onset of Season
5. Stress on Water Resources

1.2.3.1 Rise in Average Temperature

The five hottest years on record have all occurred since 1997.

Heat-trapping gases emitted by power plants, automobiles, deforestation and other sources are warming up the planet. In fact, the five hottest years on record have all occurred since 1997 and the 10 hottest since 1990, including the warmest years on record—2005 and 2010.

High temperatures are to blame for an increase in heat-related deaths and illness, rising seas, increased storm intensity, and many of the other dangerous consequences of climate change.

During the 20th century, the Earth’s average temperature rose one degree Fahrenheit to its highest level in the past four centuries—believed to be the fastest rise in a thousand years.

Scientists project that if emissions of heat-trapping carbon emissions aren’t reduced, average surface temperatures could increase by 3–10 degrees Fahrenheit by the end of the century.

Don’t let average temperatures fool you: A one-degree increase may be found in one place, a 12-degree increase in another place, and yet other areas may become much colder.

The planet’s oceans are also warming, which is causing dangerous consequences such as stronger storms, coral bleaching and rising seas.

Climate change brings health risks to the world’s most vulnerable communities.

As temperatures rise, so do the risks of heat-related illness and even death for the most vulnerable human populations.

In 2003, for example, extreme heat waves caused more than 20,000 deaths in Europe and more than 1500 deaths in India. Scientists have linked the deadly heat waves to climate change and warn of more to come.

1.2.3.2 Increase in Number of Extreme Events

Climate change will cause storms, hurricanes and tropical storms to become more intense.

Scientific research indicates that climate change will cause hurricanes and tropical storms to become more intense—lasting longer, unleashing stronger winds, and causing more damage to coastal ecosystems and communities.

Scientists point to higher ocean temperatures as the main culprit, since hurricanes and tropical storms get their energy from warm water. As sea surface temperatures rise, developing storms will contain more energy.

1.2.3.3 Increase in Occurence of Floods and Droughts

Climate change is making floods, fires and droughts more frequent and severe.

Climate change is intensifying the circulation of water on, above and below the surface of the Earth—causing drought and floods to be more frequent, severe and widespread.

Higher temperatures increase the amount of moisture that evaporates from land and water, leading to drought in many areas. Lands affected by drought are more vulnerable to flooding once rain falls.

As temperatures rise globally, droughts will become more frequent and more severe, with potentially devastating consequences for agriculture, water supply and human health. This phenomenon has already been observed in some parts of Asia and Africa, where droughts have become longer and more intense.

Hot temperatures and dry conditions also increase the likelihood of forest fires. In the conifer forests of the western United States, earlier snowmelts, longer summers and an increase in spring and summer temperatures have increased fire frequency by 400 % and have increased the amount of land burned by 650 % since 1970.

1.2.3.4 Early Onset of Season

The timely onset of the monsoon bodes well for the economy. Indeed, the monsoon was making rapid progress and was ahead of its schedule over the west coast at the time of going to press. The rainfall (until June 12, 2013) has been 17 % higher than normal and augurs well for the sowing of the kharif crop, according to Laxman Singh Rathore, Director General of the India Meteorological Department. “The arrival in the territories covered so far has been either ahead of the normal date or around the normal date. The timely onset is a positive development. Even in those areas where the monsoon has not set in, pre-monsoon showers are taking place," he says.

The south-west monsoon spread over June to September is the primary rainy season in India. Most of the country—except southern peninsula, Jammu and Kashmir and Assam—receives more than 75 % of its annual rainfall during this period. The monsoon rainfall has a direct bearing on crops across the country. Agriculture and allied sectors such as forestry and fishing account for 14 % of gross domestic product (GDP) but employ more than half of the Indian workforce.

1.2.3.5 Stress on Water Resources

The relationship between water, energy, agriculture and climate is a significant one. More and more, that relationship is falling out of balance jeopardizing food, water and energy security. Climate change is a phenomenon we can no longer deny as its effects have become increasingly evident worldwide. On the list of warmest years on record, almost every year since 1992 is included and, according to NASA and NOAA data, 2012 was the hottest.

As the earth's temperature continues to rise, we can expect a significant impact on our fresh water supplies with the potential for devastating effects on these resources. As temperatures increase, evaporation increases, sometimes resulting in droughts. As of 2013, the U.S. has been experiencing one of the most severe, multi-state, multi-year droughts in decades.

In addition, rising temperatures are melting glacial ice at an unprecedented rate. Glaciers are an important source of freshwater worldwide, and some, like those at Glacier National Park, are in danger of disappearing within the 21st century. Once these glaciers have melted away, they can't be restored. Areas that previously depended on glaciers for freshwater will then have to seek other sources.

Complicating this potential outcome is the prediction that in a warmer environment, more precipitation will occur as rain rather than snow. Although more rain than snow may seem like a plus, it could mean more frequent water shortages. When snow and ice collect on mountaintops, water is released slowly into reservoirs as it melts throughout the spring and summer. When rain falls, reservoirs fill quickly to capacity in the winter, which can also result in excess water runoff that can't be stored. Because rain flows faster than melting snow, higher levels of soil moisture and groundwater recharge are less likely to occur. Areas that rely on snowmelt as their primary freshwater source could increasingly experience water shortages, like having low water supplies by summer's end (GRACE 2014).

The greenhouse gases or GHG is responsible for raising atmospheric temperature. It also prevents the escape of heat from the earth crust. Thus increase in GHG concentration can cause global warming or cooling. The warming or cooling of atmosphere will certainly influence the regular climatic pattern. The change in climatic pattern will induce abnormality in the precipitation as well as evaporation patterns of any region which will again impose variations in the available volumes of freshwater. The reason for this increase in GHG is:

1. Increase in Industries
2. Decrease in Forest Cover
3. Decrease in Water Body
4. Increase in Number of Automobiles

Increase in Industries

Five companies in Britain produce more carbon dioxide pollution together than all the motorists on UK roads combined, according to new figures which reveal heavy industry's contribution to climate change.

A league table compiled by the Guardian identifies EON UK, the electricity generator that owns Powergen, as Britain's biggest corporate emitter of greenhouse gases. It produced 26.4 m tonnes of carbon dioxide last year—slightly more than Croatia did.

The uncontrolled extraction of natural resources, non-moderated growth in industrial activities, destruction of natural forest and water bodies followed by the rising demand for water and energy from the ever growing population to sustain their livelihood as well as luxury and the recent technological advancements has increased the stress on water resources of most of the countries in the World. The use of fossil fuel has increased many fold compared to the earlier decades and as a result amount of green house gas in the atmosphere has increased.

Germany negotiated to produce 495 m tonnes of carbon dioxide, but its companies emitted only 474 m. France produced 131 m tonnes, but had permits for 151 m (Adams and Evans 2014).

Decrease in Forest Cover

Deforestation, clearance or clearing is the removal of a forest or stand of trees where the land is thereafter converted to a non-forest use. Examples of deforestation include conversion of forestland to farms, ranches, or urban use.

Deforestation is clearing Earth's forests on a massive scale, often resulting in damage to the quality of the land. Forests still cover about 30 % of the world's land area, but swaths the size of Panama are lost each and every year.

The world's rain forests could completely vanish in a hundred years at the current rate of deforestation.

Forests are cut down for many reasons, but most of them are related to money or to people's need to provide for their families. The biggest driver of deforestation is agriculture. Farmers cut forests to provide more room for planting crops or grazing livestock. Often many small farmers will each clear a few acres to feed their families by cutting down trees and burning them in a process known as "slash and burn" agriculture.

Logging operations, which provide the world's wood and paper products, also cut countless trees each year. Loggers, some of them acting illegally, also build roads to access more and more remote forests—which leads to further deforestation. Forests are also cut as a result of growing urban sprawl.

Not all deforestation is intentional. Some is caused by a combination of human and natural factors like wildfires and subsequent overgrazing, which may prevent the growth of young trees.

Deforestation has many negative effects on the environment. The most dramatic impact is a loss of habitat for millions of species. Seventy percent of Earth's land animals and plants live in forests, and many cannot survive the deforestation that destroys their homes.

Deforestation also drives climate change. Forest soils are moist, but without protection from sun-blocking tree cover they quickly dry out. Trees also help perpetuate the water cycle by returning water vapor back into the atmosphere. Without trees to fill these roles, many former forest lands can quickly become barren deserts.

Removing trees deprives the forest of portions of its canopy, which blocks the sun's rays during the day and holds in heat at night. This disruption leads to more extreme temperatures swings that can be harmful to plants and animals.

Trees also play a critical role in absorbing the greenhouse gases that fuel global warming. Fewer forests means larger amounts of greenhouse gases entering the atmosphere—and increased speed and severity of global warming.

The quickest solution to deforestation would be to simply stop cutting down trees. Though deforestation rates have slowed a bit in recent years, financial realities make this unlikely to occur.

A more workable solution is to carefully manage forest resources by eliminating clear-cutting to make sure that forest environments remain intact. The cutting that does occur should be balanced by the planting of enough young trees to replace the older ones felled in any given forest. The number of new tree plantations is growing each year, but their total still equals a tiny fraction of the Earth's forested land (NG 2014).

Forests cover 31 % of the land area on our planet. They produce vital oxygen and provide homes for people and wildlife. Many of the world's most threatened and endangered animals live in forests, and 1.6 billion people rely on benefits forests offer, including food, fresh water, clothing, traditional medicine and shelter.

But forests around the world are under threat from deforestation, jeopardizing these benefits. Deforestation comes in many forms, including fires, clear-cutting for agriculture, ranching and development, unsustainable logging for timber, and degradation due to climate change. This impacts people's livelihoods and threatens a wide range of plant and animal species. Some 46–58 thousand square miles of forest are lost each year—equivalent to 36 football fields every minute.

Forests play a critical role in mitigating climate change because they act as a carbon sink—soaking up carbon dioxide that would otherwise be free in the atmosphere and contribute to ongoing changes in climate patterns. Deforestation undermines this important carbon sink function. It is estimated that 15 % of all greenhouse gas emissions are the result of deforestation.

Deforestation is a particular concern in tropical rainforests because these forests are home to much of the world's biodiversity. For example, in the Amazon around 17 % of the forest has been lost in the last 50 years, mostly due to forest conversion for cattle ranching. Deforestation in this region is particularly rampant near more populated areas, roads and rivers, but even remote areas have been encroached upon when valuable mahogany, gold and oil are discovered (WWF 2014).

Decrease in Water Body

In the 1600s, over 220 million acres of wetlands are thought to have existed in the lower 48 states. Since then, extensive losses have occurred, and over half of our original wetlands in the lower 48 have been drained and converted to other uses. The years from the mid-1950s to the mid-1970s were a time of major wetland loss, but since then the rate of loss has decreased.

Between 2004 and 2009, an estimated 62,300 acres of wetlands were lost in the conterminous United States. Various factors have contributed to the decline in the loss rate including implementation and enforcement of wetland protection measures and elimination of some incentives for wetland drainage. Public education and outreach about the value and functions of wetlands, private land initiatives, coastal monitoring and protection programs, and wetland restoration and creation actions have also helped reduce overall wetland losses (USEPA 2014).

The main causes of Wetland Impairment:

Hydrologic Alteration;
Urbanization (including development);
Marinas/Boats;
Industry (including industrial development);
Agriculture;
Silviculture/Timber Harvest;
Mining;
Atmospheric Deposition

Increase in Number of Automobiles

In 2012, for the first time in history, over 60 million cars passenger cars will be produced in a single year (or 165,000 new cars produced every day).

After a 9 % decline in 2009 (due to the 2008 global financial crisis), global car production immediately jumped back the following year with a 22 % increase in 2010, to then consolidate at the current 3 % yearly growth rate.

Going back in history, in 2006 there were less than 50 million passenger cars produced in the world, with an increase of 6.45 % over the previous year. The increase for 2007 was more modest, and 2008 showed a decline. Analysts from various institutes had in fact pegged the year 2007 as the year which would end the 5-year cycle (2002, 2003, 2004, 2005, 2006) of record global auto sales worldwide.

1 out of 4 cars produced in the world comes from China. China was the world's third-largest car market in 2006, as car sales in China soared by nearly 40 % to 4.1 million units. Soon thereafter, China took the lead and became the world's first-largest car market, as low vehicle penetration, rising incomes, greater credit availability and falling car prices lift sales past those of Japan. Furthermore, vehicle penetration in China still stands at only about 40 vehicles per 1000 people,

compared with approximately 700 vehicles per 1000 people in the mature markets of the G7.

More than half of the cars are produced in Asia and Oceania, whereas Europe produces almost a third.

It is estimated that over 1 billion passenger cars travel the streets and roads of the world today. The 1 billion-unit mark was reached in 2010 for the first time ever.

In the United States alone, 250,272,812 "highway" registered vehicles were counted in 2010, of which 190,202,782 passenger cars.

In 2013 the percentage of passenger and commercial car produced is maximum than the last 15 years (Statista 2014).

The Figs. 1.4, 1.5 and 1.6 depicts the automobile production from top five countries in the year 2013, 2011 and 2000 respectively (WM 2014). The increase in rate of production can be visible if the three images were compared.

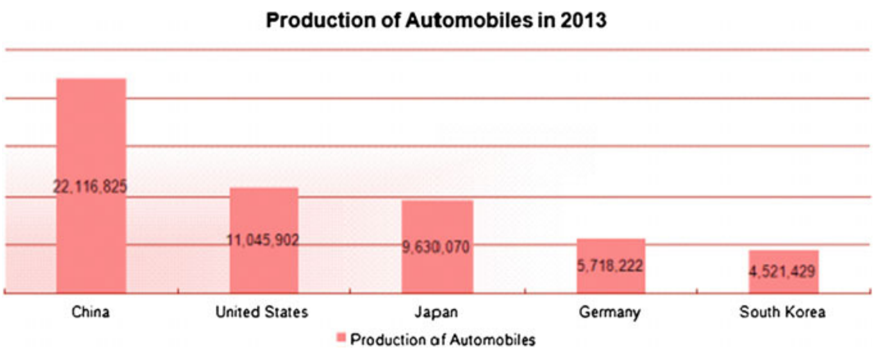

Fig. 1.4 Production of automobiles in 2013

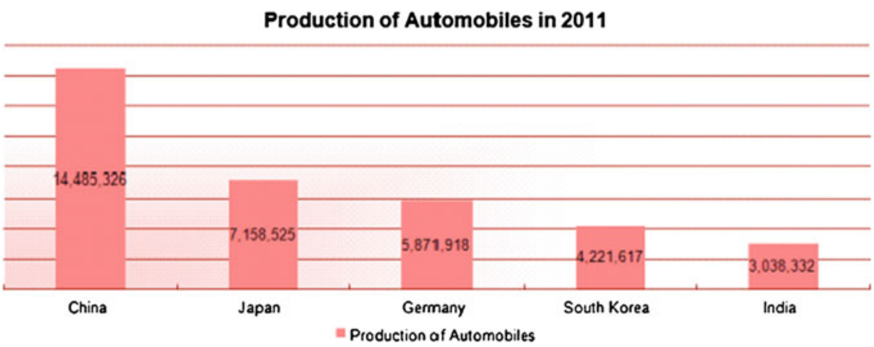

Fig. 1.5 Production of automobiles in 2011

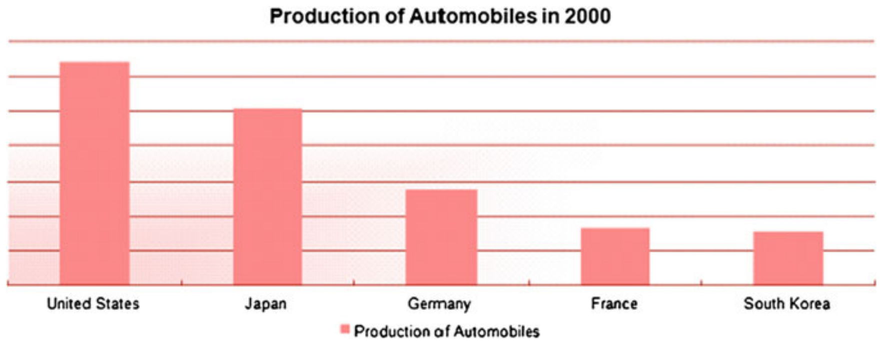

Fig. 1.6 Production of automobiles in 2000

1.2.4 Mismanagement of Available Water Resources

While the amount of freshwater on the planet has remained fairly constant over time—continually recycled through the atmosphere and back into our cups—the population has exploded.

This means that every year competition for a clean, copious supply of water for drinking, cooking, bathing, and sustaining life intensifies.

Freshwater makes up a very small fraction of all water on the planet. While nearly 70 % of the world is covered by water, only 2.5 % of it is fresh. The rest is saline and ocean-based. Even then, just 1 % of our freshwater is easily accessible, with much of it trapped in glaciers and snowfields. In essence, only 0.007 % of the planet's water is available to fuel and feed its 6.8 billion people.

Keeping in view of the above scenario, the question is will it be possible to provide enough water to the ever-growing population (predicted to be at least 9 billion by 2050 (UN Medium Hypothesis) using a volume which will be roughly the same as it is now?

The impact of climate change, urbanization and water pollution is raising stress on fresh water resources of the World.

Even after the impact of the above causes there are some amount of water available in every country of the World. But that amount is also non-optimally utilize. There is no specific methods for allocation of water resources to different kind of consumers. Still monetory and political gains are considered before allocation of the scarce resources. In some places uniform allocation of water is followed. In few places water metering concept is adopted but charge taken from the consumers is nominal and often nature of consumers are not considered before fixing of tariff.

Thus due to the non-optimal allocation of the scarce resource a sufficient amount of water available for use is also wasted. The reason for this mismanagement is:

1. Non-Optimal Allocation of Water Resources
2. Drawback with the Indicators

1.2.4.1 Non-optimal Allocation of Water Resources

A major concern of non optimal allocation of water resources is there are no specific methodology adopted for allocation of the resources. All though their are some indicators available to track and monitor the status of the availability of water. But in most of them the effect is given more importance than the causes.

1.2.4.2 Drawback with the Indicators

The major drawback of the indicators explained above is most of them have not explicitly considered spatial and temporal variability of the related parameters (e.g. Index of Water scarcity, Falkenmar's Water Availability Indicators). Also they have not considered the water quality while calculating the availability of water resources which can be consumed for different purposes (e.g. WAI). Moreover the indicators has the following limitations:

1. The input parameters are uniformly weighted or the importance of all the input parameters are taken as equal. But in reality different parameters has different level of sensitivity towards the determination of availability of usable water.
2. Even if there are more than one indicator and the result of which is aggregated to find the final output all the indicators are treated equally (e.g. WPI).

1.3 Objective of the Present Study

The drawback of the available indicators and the present situation of availability of water resources all over the world encouraged the author to develope an indicator which will consider both spatial and temporal variability, quality of water as well as the different types of uses while estimating the severity of water scarcity in a region.

All the parameters are not equally weighted in this indicator. The weights of importance for each of the selected parameters are determined in directly proportional manner to their capability to influence the availability of usable fresh water. The major objective of the present investigation is:

1. To develop a Weighted Cognitive Indicator for Representing Status of the Water Shortage
2. To identify the priorities of the related parameters of water availability

1.3.1 To Develop a Weighted Cognitive Indicator for Representing Status of the Water Shortage

The indicator is developed to represent the status of the water shortage as a function of urbanization, climatic parameter and water quality.

Advanced techniques like Multi Criteria Decision Making (MCDM) was utilized to determine the importance of each of the parameters.

The indicator was induced a cognitive capability by the introduction of Artificial Neural Networks (ANN).

The index was validated by sensitivity and scenario analysis where three cases having different levels of urbanization was analyzed with the help of the indicator under six different climate change scenarios as proposed by Inter-Governmental Panel of Climate change (IPCC). Further the new indicator is developed in such a manner that it becomes:

1. a function of Urbanization
2. a function of Climatic Parameters
3. a function of Water Pollution

1.3.1.1 To Develop the Indicator as a Function of Urbanization

The following parameters are selected to make the indicator a function of urbanization. The inclusion of the parameters enabled the index to represent the impact of change in urbanization. As amplitude of the curve representing the temporal variability of the parameters the indicator was able to indicate the impact of temporal change in urbanization also:

1. Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)
2. Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)
3. Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)
4. Percentage Impervious Area (last 10 year) (A)
5. Annual Average Area of Canopy (Ac)

1.3.1.2 To Develop the Indicator as a Function of Climatic Parameters

The next few parameters are considered to develop the indicator a function of climatic parameter and to provide the index a capability to represent the impact of climate change. The inclusion of the amplitudes rather than discrete data of the input parameters enabled the indicator to depict the impact of temporal variability of climatic parameters.:

1. Frequency of Troughs in Annual Hyetograph (P)
2. Frequency of Peak in Annual Hydrograph (Q)

1.3.1.3 To Develop the Indicator as a Function of Water Pollution

Water Quality Index (WQI) is an indicator proposed by National Sanitation Foundation (NSF) to represent the overall quality of water. The values of WQI is determined for different purposes and uses of water. In the present study WQI was determined to represent the usability of available water for industrial purposes. If the water is required to be used in agriculture and domestic purposes it is taken that necessary treatment arrangements can be provided so that the quality of the water can be upgraded for agriculture or domestic consumption. Here also to represent the temporal variability the amplitudes rather than discrete data was considered to calculate the value of the indicators.

1. Frequency of Troughs in Annual Water Quality Index curve (WQI)

1.3.2 To Identify the Priorities of the Related Parameters of Water Availability

The priority values or the weights of importance of all the parameters were calculated first before the estimation of the indicator value to represent the status of water shortage.

The reason for determination of priority values can be contributed to the fact that in case of mitigative action to prevent further degradations and reversal of the situations the developers can concentrate on the most important parameters only and can compromise on the least important factors within the selected parameters.

This can save lot of money and manpower and can provide an opportunity for optimally tackling the situation of water shortage.

1.4 Brief Methodology

1. Identification of most influential parameters which can impact on availability of water by Expert survey, Literature survey and Stakeholder survey
2. Assigning weight vectors to the identified parameters according to their importance in controlling the intensity of shortage water.

3. The weight vector of the selected parameter is determined with the help of aggregation methods like: Analytical Hierarchy Process and Fuzzy Logic Decision Making.
4. The index was formulated as per the weight function concept where the weight vectors are taken as the weights and the factors are taken as the variable. This index is developed in such a manner that it became coherent with the severity of water shortage.
5. An ANN model was also developed for prediction of the value of the index with respect to different real life situations that may exist in various regions of the World.
6. Once the index is developed the sensitivity of the same will be carried out.
7. A scenario analysis will be conducted with respect to climate change on three different locations having various level of urbanization.

1.4.1 MCDM

The advantage of MCDM technology is applied in the present study. The MCDM techniques like Analytical Hierarchy Process (AHP) and Fuzzy Logic Decision Making (FLDM) was applied after the parameters are selected by literature, expert and stakeholder's survey.

In the present study; Expert Survey, Stakeholders Survey, Literature Review, Sponsors Preference and Data Availability are taken as the Criteria of the decision making process.

The alternative of the MCDM was the parameters selected by the Expert, Literature and Stakeholder Survey. The parameters which have been considered as the Alternatives are given below:

Fquency of Troughs in Annual Hyetograph (P)
Frequency of Peak in Annual Hydrograph (Q)
Frequncy of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)
Percentage Impervious Area (last 10 year) (A)
Annual Average Area of Canopy (Ac)
Frequency of Troughs in Annual Water Quality Index curve (WQI)

1.4.2 Artificial Neural Network

After the priority values of the selected parameters were determined a neural network model was prepared to estimate the indicator for all type of situations that can be represented by the selected parameters. The input of the model are the selected parameters of the indicator and the output is the weight function of the parameters. This addition will remove the need of applying MCDM again and again once a new location is required to be analyzed if the locations are considered as the Sub-Alternatives.

1.4.3 Validation of the Indicators by Sensitivity Analysis

The index was validated with the help of sensitivity analysis where the sensitivity of the selected parameters were analyzed and compared with the priority values of the parameters. For successful validation the priority values and sensitivity of the parameter has to be directly correlated.

1.4.4 Application and Validation of the Indicator with Respect to Climate Change Scenarios in Three Different Study Areas

Three areas were at first selected for calculation of the value of the indicator. The areas were selected in such a manner that all three have different level of urban population.

Three selected regions are:

1. Farakka Barrage on River ganges: Medium Level of Urban Population
2. Mahi River Dam on Mahi River: High Level of Urban Population
3. Vaigai Dam in River Periyar: Low Level of Urban Population

Next according to the IPCC proposed climate change scenario A2 and B2 the value of the indicator was calculated for three time slabs under both of the scenarios.

The value of the indicator will represent the impact of climate change on three regions having different level of population density.

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Chapter 2
Multi Criteria Decision Making

Abstract 'Decision Making is the act of choosing between two or more courses of action'. However, it must always be remembered that there may not always be a 'correct' decision among the available choices. There may have been a better choice that had not been considered, or the right information may not have been available at the time. Multiple-criteria evaluation problems consist of a finite number of alternatives, explicitly known in the beginning of the solution process. In Multiple-criteria design problems (multiple objective mathematical programming problems) the alternatives are not explicitly known. An alternative (solution) can be found by solving a mathematical model. The number of alternatives is either infinite or not countable (when some variables are continuous) or typically very large if countable (when all variables are discrete). But both kind of problems are considered as a subclasses of Multi Criteria Decision Making problems. The MCDM problems can also be divided into two major classes with respect to the way the weights of the alternatives are determined: Compensatory and Outranking Decision Making. The example of the former is Analytical hierarchy Process (AHP) and the latter is ELimination and Choice Expressing Reality (ELECTRE). The basic working principle of any MCDM method is same: Selection of Criteria, Selection of Alternatives, Selection of Aggregation Methods and ultimately Selection of Alternatives based on weights or outranking.

Keywords Fuzzy decision making · Analytical hierarchy process · Outranking methods · Decision making in water resources

2.1 Definition

MCDM or MCDA are well-known acronyms for multiple-criteria decision-making and multiple-criteria decision analysis. MCDM is concerned with structuring and solving decision and planning problems involving multiple criteria. The purpose is to support decision makers facing such problems. Typically, there does not exist a

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unique optimal solution for such problems and it is necessary to use decision maker's preferences to differentiate between solutions.

2.2 Steps of Decision Making

A decision making process involves the following steps to be followed:

1. Identifying the objective/goal of the decision making process
2. Selection of the Criteria/Parameters/Factors/Decider
3. Selection of the Alternatives
4. Selection of the weighing methods to represent importance
5. Method of Aggregation
6. Decision making based on the Aggregation results

2.3 Working Principle

The MCDM process follows a common working principle as described below:

1. **Selection of Criteria**
   Selected criteria must be:

   Coherent with the decision
   Independent of each other
   Represented in same scale
   Measurable
   Not Unrelated with the alternatives

2. **Selection of Alternatives**
   Selected alternatives must be:

   Available
   Comparable
   Real not Ideal
   Practical/Feasible

3. **Selection of the Weighing Methods to Represent Importance**
   The weight determination methods can be either compensatory or outrankable.
   Example of Compensatory Method:

   Analytical Hierarchy Process (AHP), Fuzzy Multi-Criteria Decision Making Process (FDM) etc.

   Example of Out-ranking Method:

   ELimination and Choice Expressing Reality (ELECTRE), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHUS)

4. **Method of Aggregation**

   Can be a Product
   Can be an Average
   Can be a Function
   The result of this aggregation will actually separate the best alternative from the available options

2.4 Types of MCDM

The MCDM methods can be classified into two groups as explained in the next section.

2.4.1 Compensatory Method

A rational decision-making model in which choices are systematically evaluated on various criteria. Attractive attributes of an alternative can compensate for less attractive ones—a systematic decision-making procedure has to be followed. A compensatory model because a positive score on one attribute can outweigh a negative score on another attribute.

A compensatory decision involves the consumer "trading off" good and bad attributes of a product. For example, a car may have a low price and good gas mileage but slow acceleration. If the price is sufficiently inexpensive and gas efficient, the consumer may then select it over a car with better acceleration that costs more and uses more gas. Occasionally, a decision will involve a non-compensatory strategy. For example, a parent may reject all soft drinks that contain artificial sweeteners. Here, other good features such as taste and low calories cannot overcome this one "non-negotiable" attribute.

The amount of effort a consumer puts into searching depends on a number of factors such as the market (how many competitors are there, and how great are differences between brands expected to be?), product characteristics (how important is this product? How complex is the product? How obvious are indications of quality?), consumer characteristics (how interested is a consumer, generally, in analyzing product characteristics and making the best possible deal?), and situational characteristics (as previously discussed).

2.4.2 Outranking Methods

A rather different approach from any of those discussed so far has been developed in France and has achieved a fair degree of application in some continental

European countries. It depends upon the concept of outranking. The methods that have evolved all use outranking to seek to eliminate alternatives that are, in a particular sense, dominated’. However, unlike the straightforward dominance idea outlined in Sect. 4.5, dominance within the outranking frame of reference uses weights to give more influence to some criteria than others. One option is said to outrank another if it outperforms the other on enough criteria of sufficient importance (as reflected by the sum of the criteria weights) and is not outperformed by the other option in the sense of recording a significantly inferior performance on any one criterion. All options are then assessed in terms of the extent to which they exhibit sufficient outranking with respect to the full set of options being considered as measured against a pair of threshold parameters.

An interesting feature of outranking methods is that it possible, under certain conditions, for two options to be classified as ‘incomparable’ (‘difficult to compare’ is probably a better way to express the idea). Incomparability of two options is not the same as indifference between two options and might, for example, be associated with missing information at the time the assessment is made. This is not an unlikely occurrence in many decision making exercises. Building this possibility into the mathematical structure of outranking allows formal analysis of the problem to continue while neither imposing a judgement of indifference which cannot be supported nor dropping the option entirely, simply because information is not to hand. The main concern voiced about the outranking approach is that it is dependent on some rather arbitrary definitions of what precisely constitutes outranking and how the threshold parameters are set and later manipulated by the decision maker.

The outranking concept does, however, indirectly capture some of the political realities of decision making. In particular it downgrades options that perform badly on any one criterion (which might in turn activate strong lobbying from concerned parties and difficulty in implementing the option in question). It can also be an effective tool for exploring how preferences between options come to be formed.

2.5 Examples

AHP and FLDM are two most popular example of Compensatory MCDM which are widely used to solve decision making problems and in various decision support systems worldwide.

2.5.1 Analytical Hierarchal Process (AHP)

AHP has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education.

Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well or poorly understood—anything at all that applies to the decision at hand.

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations.

The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques.

In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

2.5.1.1 Inventor

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then.

2.5.1.2 Working Principle

The first step in the analytic hierarchy process is to model the problem as a hierarchy. In doing this, participants explore the aspects of the problem at levels from general to detailed, then express it in the multileveled way that the AHP requires. As they work to build the hierarchy, they increase their understanding of the problem, of its context, and of each other's thoughts and feelings about both.

Hierarchies Defined

A hierarchy is a stratified system of ranking and organizing people, things, ideas, etc., where each element of the system, except for the top one, is subordinate to one or more other elements. Though the concept of hierarchy is easily grasped intuitively, it can also be described mathematically. Diagrams of hierarchies are often shaped roughly like pyramids, but other than having a single element at the top, there is nothing necessarily pyramid-shaped about a hierarchy.

Human organizations are often structured as hierarchies, where the hierarchical system is used for assigning responsibilities, exercising leadership, and facilitating communication. Familiar hierarchies of "things" include a desktop computer's tower unit at the "top", with its subordinate monitor, keyboard, and mouse "below."

In the world of ideas, we use hierarchies to help us acquire detailed knowledge of complex reality: we structure the reality into its constituent parts, and these in turn into their own constituent parts, proceeding down the hierarchy as many levels as we care to. At each step, we focus on understanding a single component of the whole, temporarily disregarding the other components at this and all other levels. As we go through this process, we increase our global understanding of whatever complex reality we are studying.

Think of the hierarchy that medical students use while learning anatomy—they separately consider the musculoskeletal system (including parts and subparts like the hand and its constituent muscles and bones), the circulatory system (and its many levels and branches), the nervous system (and its numerous components and subsystems), etc., until they've covered all the systems and the important subdivisions of each. Advanced students continue the subdivision all the way to the level of the cell or molecule. In the end, the students understand the "big picture" and a considerable number of its details. Not only that, but they understand the relation of the individual parts to the whole. By working hierarchically, they've gained a comprehensive understanding of anatomy.

Similarly, when we approach a complex decision problem, we can use a hierarchy to integrate large amounts of information into our understanding of the situation. As we build this information structure, we form a better and better picture of the problem as a whole.

2.5.1.3 Application

The AHP method of decision making has been applied in water resources planning and management (Hajkowicz and Collins 2007), wetland management (Gamini 2004), selection of desalination plants (Hajeeh and Al-Othman 2005), agriculture management (Giri and Nejadhashemi 2014) etc. Among them the application of AHP in evaluation of rural water supply system, desalination plants and building resilience to water scarcity is discussed in more detail to show the way AHP method can be applied to solve decision making problems in water resources.

1. Resilience in water scarcity
2. Evaluation of desalination plants
3. Evaluation of Rural Water Supply

Resilience in Water Scarcity

Agricultural water management needs to evolve in view of increased water scarcity, especially when farming and natural protected areas are closely linked. In the study site of Doñana (southern Spain), water is shared by rice producers and a world heritage biodiversity ecosystem. Our aim is to contribute to defining adaptation strategies that may build resilience to increasing water scarcity and minimize water conflicts among agricultural and natural systems. The analytical framework links a participatory process with quantitative methods to prioritize the adaptation options. Bottom-up proposed adaptation measures are evaluated by a multi-criteria analysis (MCA) that includes both socioeconomic criteria and criteria of the ecosystem services affected by the adaptation options.

Criteria weights are estimated by three different methods—analytic hierarchy process, Likert scale and equal weights—that are then compared. Finally, scores from an MCA are input into an optimization model used to determine the optimal land-use distribution in order to maximize utility and land-use diversification according to different scenarios of funds and water availability. While our results show a spectrum of perceptions of priorities among stakeholders, there is one overriding theme that is to define a way to restore part of the rice fields to natural wetlands. These results hold true under the current climate scenario and even more so under an increased water scarcity scenario (de Jalón et al. 2014).

Evaluation of Desalination Plants

Seawater desalination plants have been utilized to supply fresh water to the Gulf Cooperation Council countries since the early 1950s. In spite of the fact that there are several types of desalination technology that can be used more efficiently and economically, one type of desalination technology, namely multi-stage flash, has been used extensively in the region. This work is an attempt to identify the most suitable technology for the specific use by soliciting expert opinions. Based on several relevant factors, the analytical hierarchy process (AHP) was utilized to select the most appropriate technology for seawater desalination. The selection process in this study was limited to seawater feed and seven factors and four commercially available desalination technologies, i.e., multi-stage flash, multi-effect desalination, vapor compression and reverse osmosis (Hajeeh and Al-Othman 2005).

Evaluation of Rural Water Supply

Some rural water supply (RWS) schemes were constructed in 2002 in the Dhule district of Maharashtra State in India as part of pilot projects launched in 68 districts throughout the country with financial assistance from the Government of India. The present research is derived from an investigation conducted on 11 such RWS schemes constructed during the period of 2002–2005 and aims to establish a composite sustainable management index for assessing long-term sustainability in the context of the level of service and evaluating the current performance level of piped-water supply schemes. The identification of factors influencing sustainable management is a prerequisite for developing a composite index. Various investigators have worked on the sustainability of RWS systems worldwide considering different sets of factors and subfactors. In this research, a set of five factors and 25 subfactors is considered. Two factors, though being a part of functional sustainability, are excluded in building the index; however, they are used to validate the results. The analytical hierarchy process is used for the development of metrics in decision making, i.e., for establishing the weight of factors and subfactors. The proposed model enables RWS utilities to identify the key sustainable management factors and provides a framework for aggregating various factors and subfactors into a composite sustainable management index. The outcome may also be used to identify the factors/subfactors that have potential for improvement and thus be helpful in finalizing the strategies for enhancing the functional sustainability of the system. The results demonstrate that nine subfactors out of the 25 dominate in all 11 RWS utilities studied. The RWS utilities are classified on the basis of their performance as high, moderate, or low in sustainability. The derived factors' sustainability index may be useful for decision makers to discover the tradeoffs between them. The derived index may be a rational and transparent basis for recommending postconstruction support for a rural water utility. The limitations of the presented research are the comprehensiveness and effectiveness of the data considered, being slightly biased to the accessibility of information, in the absence of a more rational data-recording system (Dwivedi and Bhadauria 2014).

2.5.2 Fuzzy Logic Decision Making (FLDM)

Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Irrationality can be described in terms of what is known as the fuzzjective.

2.5.2.1 Inventor

The term "fuzzy logic" was introduced with the 1965 proposal of fuzzy set theory by Lotfi A. Zadeh. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. Fuzzy logics had, however, been studied since the 1920s, as infinite-valued logics—notably by Łukasiewicz and Tarski (Pelletier 2000).

2.5.2.2 Working Principle (Calvin 2011)

The logic with which people decide can be represented by the following algorithm:

$$\begin{aligned}&\textbf{If P}, \textbf{then Q}.\\&\textbf{P}.\\&\textbf{Therefore}, \textbf{Q}.\end{aligned}$$

The reasoning is strict as Q can exist only if P exists. This type of conditions are crisp and in many cases such rigid conditions does not represent the true situation. This problem is solved by Fuzzy Logic. Where Q can mostly exist if P is mostly valid.

$$\begin{aligned}&\textbf{If P}, \textbf{then Q}.\\&\boldsymbol{mostly}\ \textbf{P}.\\&\textbf{Therefore}, \boldsymbol{mostly}\ \textbf{Q}.\end{aligned}$$

where P and Q are now fuzzy numbers. The reasoning above requires a set of rules to be defined. These rules are linguistic rules to relate different fuzzy sets and numbers. The general form of these rules are: "if x is A then y is B," where x and y are fuzzy numbers in the fuzzy sets A and B respectively.

The linguistic rules are used to find the relationship between input and output whose relationship is fuzzy. The actual answer is given by method of aggregation and inference as demonstrated by Mamdani, Larsen, Takagi-Sugeno-Kang, and Tsukamoto and explained with the below statement:

$$\text{If } x \text{ is } \mathbf{A}\boldsymbol{i} \quad \text{then} \quad y \text{ is } \mathbf{B}\boldsymbol{i}, \quad i = 1, 2, \ldots, n$$

Defuzz method	Result
Centroid	7.319
Bisector	7.230
Largest of max	9
Smallest of max	6
Middle of max	7.5

2.5.2.3 Application

Almost any control system can be replaced with a fuzzy logic based control system. This may be overkill in many places however it simplifies the design of many more complicated cases. So fuzzy logic is not the answer to everything, it must be used when appropriate to provide better control. If a simple closed loop or PID controller works fine then there is no need for a fuzzy controller. There are many cases when tuning a PID controller or designing a control system for a complicated system is overwhelming, this is where fuzzy logic gets its chance to shine.

One of the most famous applications of fuzzy logic is that of the Sendai Subway system in Sendai, Japan. This control of the Nanboku line, developed by Hitachi, used a fuzzy controller to run the train all day long. This made the line one of the smoothest running subway systems in the world and increased efficiency as well as stopping time. This is also an example of the earlier acceptance of fuzzy logic in the east since the subway went into operation in 1988.

The most tangible applications of fuzzy logic control have appeared commercial appliances. Specifically, but not limited to heating ventilation and air conditioning (HVAC) systems. These systems use fuzzy logic thermostats to control the heating and cooling, this saves energy by making the system more efficient. It also keeps the temperature more steady than a traditional thermostat.

Another significant area of application of fuzzy control is in industrial automation. Fuzzy logic based PLCs have been developed by companies like Moeller. These PLCs, as well as other implementations of fuzzy logic, can be used to control any number of industrial processes.

For some examples see: http://www.fuzzytech.com/e/e_a_plc.html.

Fuzzy logic also finds applications in many other systems. For example, the MASSIVE 3D animation system for generating crowds uses fuzzy logic for artificial intelligence.

This program was used extensively in the making of the Lord of the Rings trilogy as well as The Lion, The Witch and the Wardrobe films.

As a final example of fuzzy logic, it can be used in areas other than simply control. Fuzzy logic can be used in any decision making process such as signal processing or data analysis. An example of this is a fuzzy logic system that analyzes a power system and diagnoses any harmonic disturbance issues. The system analyzes the fundamental voltage, as well as third, fifth and seventh harmonics as well as the temperature to determine if there is cause for concern in the operation of the system.

Fuzzy Logic decision Making has been widely used in many areas of science and engineering. Three example application is discussed from the following fields of application:

- Water Quality
- Urban Water Management
- Reservoir Operation

Water Quality

Agharaabi et al. (2014) presents the use of two multi-criteria decision-making (MCDM) frameworks based on hierarchical fuzzy inference engines for the purpose of assessing drinking water quality in distribution networks. Incommensurable and uncertain water quality parameters (WQPs) at various sampling locations of the water distribution network (WDN) are monitored. Two classes of WQPs including microbial and physicochemical parameters are considered. Partial, incomplete and subjective information on WQPs introduce uncertainty to the water quality assessment process. Likewise, conflicting WQPs result in a partially reliable assessment of the quality associated with drinking water. The proposed methodology is based on two hierarchical inference engines tuned using historical data on WQPs in the WDN and expert knowledge. Each inference engine acts as a decision-making agent specialized in assessing one aspect of quality associated with drinking water. The MCDM frameworks were developed to assess the microbial and physicochemical aspects of water quality assessment. The MCDM frameworks are based on either fuzzy evidential or fuzzy rule-based inference. Both frameworks can interpret and communicate the relative quality associated with drinking water, while the second is superior in capturing the nonlinear relationships between the WQPs and estimated water quality. More comprehensive rules will have to be generated prior to reliable water quality assessment in real-case situations. The examples presented here serve to demonstrate the proposed frameworks. Both frameworks were tested through historical data available for a WDN, and a comparison was made based on their performance in assessing levels of water quality at various sampling locations of the network.

Urban Water Management

Engineering is currently expanding its conceptual boundaries by accepting the challenge of interdisciplinarity, while often adopting social and biological concepts in developing tools (e.g. evolutionary optimization or interactive autonomous agents) or even world views (e.g. co-evolution, resilience, adaptation). The emerging socio-technical knowledge domain is still very much restricted by partial knowledge associated with the lack of long-term transdisciplinary research effort and the unavailability of robust, integrated tools able to cover both the technical and the socio-economic domains and to act as 'thinking platforms' for long-term scenario planning and strategic decision making under (high-order) uncertainties. Here we present an example of a toolkit that attempts to bridge this gap focusing on urban water (UW) systems and their management. The toolkit consists of three tools: the UW Optioneering Tool (UWOT); the UW Agent Based Modelling Platform (UWABM); and the UW System Dynamic Environment (UWSDE). The tools are briefly presented and discussed, focusing on interactions and data flows between them and their typical results are illustrated through a case study example. A further tool (a Cellular Automata Based Urban Growth Model) is currently under development and an early coupling with the other tools is also discussed. It is argued that this type of extended model fusion, beyond what has traditionally been thought of as 'integrated modelling' in the engineering domain is a new frontier in the understanding of environmental systems and presents a promising, emerging field in modelling interactions between our societies and cities, and our environment (Christos 2014).

Reservoir Operation

Imprecision is often involved in reservoir-systems operation, as these systems are too complex to be defined in precise terms. Fuzzy programming has an essential role in fuzzy modeling, which can formulate uncertainty in the actual environment. In this study, a multipurpose, single-reservoir operation model is developed by assuming triangular fuzzy-number distribution of the parameters. The applicability of the model is demonstrated through the case study of the Jayakwadi reservoir stage II, Maharashtra State, India. The reservoir-operation model considers two objectives: maximization of the releases for irrigation and maximization of the releases for hydropower generation. The model is solved for a vector of a triangular fuzzy-number by giving a priority to each objective. By individual optimization, the fuzzy optimal solution is obtained for each objective in the form of a triangular fuzzy-number distribution. This solution is defuzzified to obtain the crisp values, which are further used to develop a fuzzy-compromised model. The compromised model is solved for the maximization of the degree of satisfaction (λ) by simultaneously optimizing both of the objectives. The degree of satisfaction (λ) achieved is 0.67, and the corresponding values for irrigation releases and hydropower releases are equal to the 388.54 and 195.19 Mm^3, respectively (Kamodkar and Regulwar 2014).

2.6 Limitations

The major limitation of the AHP and FLDM is each of the method accept either qualitative or quantitative ratings while comparing the parameters with each other.

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Chapter 3
Artificial Neural Network

Abstract Artificial Neural network or ANN is a very popular method for predictive or optimization or simulation objectives. ANN mimics the human nervous system to solve problems in a parallel manner. ANN are known to be adaptable with situations, flexible with data and efficient enough for predicting any kind of problems. The limitation of ANN lies into the overdependence on data for learning the problem. Also there is no specific rule for the selection of activation function and number of hidden layers. However the application of ANN is still growing and various new forms of ANN is now utilized to solve problems from engineering, science as well as literature. The new methods mainly tries to solve the above discussed limitations by merging ANN with other or developing completely new algorithms.

Keywords Feedforward neural networks · Training algorithms · Hidden layers · Classification of neural networks

3.1 Definition

In machine learning and related fields, artificial neural networks (ANNs) are computational models inspired by an animal's central nervous systems (in particular the brain) which is capable of machine learning as well as pattern recognition.

Mathematical Representation of ANN

$$\mathrm{Zk} = \mathrm{fA}(\ \mathrm{wjk} \times \mathrm{Yj}\ +\ \mathrm{bk}) \tag{3.1}$$

where

$$\mathrm{Yj} = \mathrm{gA}(\ \mathrm{hij} \times \mathrm{Xi} + \mathrm{aj})\ \text{ for multi layered network} \tag{3.2}$$

$$\mathrm{Yj} = \mathrm{gA}(\ \mathrm{hij} \times \mathrm{Xi} + \mathrm{aj})\ \text{ for single layered network} \tag{3.3}$$

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where Y is the output, f and g are the activation function, X is the input, w and h are the weightage and a, b are the bias. i = 1…n, j = 1…h.

3.2 Limitations

Like any technique, neural networks have certain drawbacks which are now highlighted to enable authors for an educated decision of selecting ANN for prediction purpose.

- Since the NN finds a general approximation of a solution, there is a small error usually associated with all the NN outputs.
- The full nature of Neural Networks is still not fully understood, and thus current research must take an experimental approach to the problem of performance.
- At present, there are not any NN computers available at a reasonable cost.
- Neural networks errors vary, depending upon the architecture.
- Neural networks require lengthy training times.

Neural networks provide the best results when used to complement current computing techniques, which contain poorly defined problems. The current computing schemes can handle well defined problems, and the neural networks can deal with the unmodeled problems (Fig. 3.1).

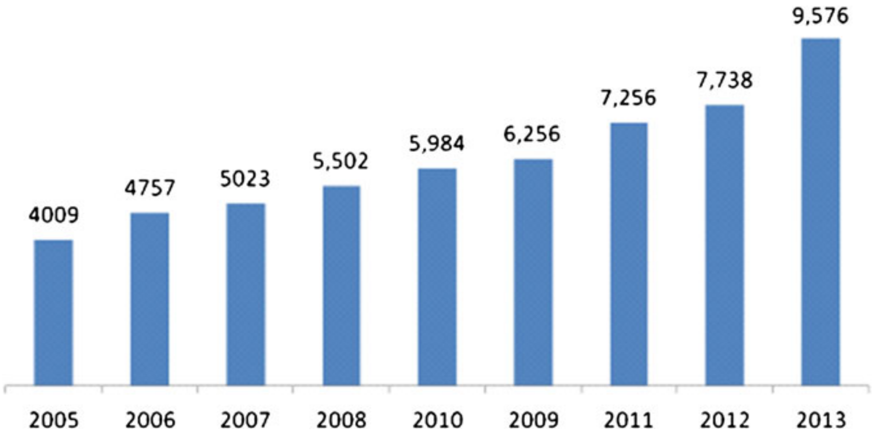

Fig. 3.1 shows the number of ANN-related papers published during the period 2005–2013. The apparent increasing trend demonstrates the growing popularity of this modelling method in solving complex, nonlinear problems

3.3 Working Principle

1. **Selection of the Model Topology:**

ANN have an input and output layer. Between this two layers, lies the hidden layer which actually separates the ANN model from the other linear and non-linear models. Selection of the number of hidden layers influences the efficiency of the model. More the number of hidden layers more complex but efficient will be the model and vice versa.

2. **Training for determination of the optimal value of the weights.**

The weight of the inputs are changed to equate the predicted value with the desired value of the output. Whenever both the desired and predicted value becomes equal or nearly equal to the satisfaction of the developer the training is stopped.

3. **Validation of the Model by predicting the known outputs.**

3.4 Types of ANN

The neural networks can be divided into three classes with respect to the way the signals are processed in the architecture.

Networks based on supervised and unsupervised learning

Supervised Learning

The network is supplied with a sequence of both input data and desired (target) output data network is thus told precisely by a "teacher" what should be emitted as output.

The teacher can during the learning phase "tell" the network how well it performs ("reinforcement learning") or what the correct behavior would have been ("fully supervised learning").

Self-organization or Unsupervised Learning

A training scheme in which the network is given only input data, network finds out about some of the properties of the data set, learns to reflect these properties in its output. e.g. the network learns some compressed representation of the data. This type of learning presents a biologically more plausible model of learning.

Networks based on Feedback and Feedforward Connections

Feedback Networks Adapting to Unsupervised Learning:

- Binary Adaptive Resonance Theory (ART1)
- Analog Adaptive Resonance Theory (ART2, ART2a)
- Discrete Hopfield (DH)
- Continuous Hopfield (CH)

- Discrete Bidirectional Associative Memory (BAM)
- Kohonen Self-organizing Map/Topology-preserving map (SOM/TPM)

Feedforward-only Networks Adapting to Unsupervised Learning

- Learning Matrix (LM)
- Sparse Distributed Associative Memory (SDM)
- Fuzzy Associative Memory (FAM)
- Counterpropagation (CPN)

Feedback Networks adapting to Supervised Learning

- Brain-State-in-a-Box (BSB)
- Fuzzy Cognitive Map (FCM)
- Boltzmann Machine (BM)
- Backpropagation through time (BPTT)

Feedforward-only Networks adapting to Supervised Learning

- Perceptron
- Adaline, Madaline
- Backpropagation (BP)
- ArtmapLearning Vector Quantization (LVQ)
- Probabilistic Neural Network (PNN)
- General Regression Neural Network (GRNN)

3.5 Applications

3.5.1 Drought Management

Dehghani et al. (2014) developed two scenarios of drought forecast. In the first scenario, the time series of monthly streamflow were converted into the Standardized Hydrological Drought Index (SHDI), a similar index to the well-known Standardized Precipitation Index (SPI). Multi-layer feed-forward artificial neural network (FFANN) was trained with the SHDI time series to forecast the hydrological drought of Karoon River in southwestern Iran.

3.5.2 Water Supply System

The efficient operation and management of an existing water supply system require short-term water demand forecasts as inputs. Conventionally, regression and time series analysis have been employed in modelling short-term water demand forecasts. The relatively new technique of artificial neural networks has been proposed as an efficient tool for modelling and forecasting in recent years. Jain et al. (2001)

tried to investigate the relatively new technique of artificial neural networks for use in forecasting short-term water demand at the Indian Institute of Technology, Kanpur. Other techniques investigated in this study include regression and time series analysis for comparison purposes.

3.5.3 Landuse and Landcover Change

Nowadays, cities are expanding and developing with a rapid growth, so that the urban development process is currently one of the most important issues facing researchers in urban issues. In addition to the growth of the cities, how land use changes in macro level is also considered. Studying the changes and degradation of the resources in the past few years, as well as feasibility study and predicting these changes in the future years may play a significant role in planning and optimal use of resources and harnessing the non-normative changes in the future.

There are diverse approaches for modeling the land use and cover changes among which may point to the Markov chain model. Razavi (2014) in his study observed the changes in land use and land cover in Kermanshah City, Iran during 19 years using multi-temporal Landsat satellite images in 1987, 2000 and 2006, side information and Markov Chain Model. Results shows the decreasing trend in range land, forest, garden and green space area and in the other hand, an increased in residential land, agriculture and water suggesting the general trend of degradation in the study area through the growth in the residential land and agriculture rather than other land uses. Finally, the state of land use classes of next 19 years (2025) was anticipated using Markov Model. Results obtained from changes prediction matrix based on the maps of years 1987 and 2006 it is likely that 82 % of residential land, 58.51 % of agriculture, 34.47 % of water, 8.94 % of green space, 30.78 % of gardens, 23.93 % of waste land and 16.76 % of range lands will remain unchanged from 2006 to 2025, among which residential lands and green space have the most and the least sustainability, respectively.

3.5.4 Groundwater Quality

Mukherjee and Veer (2014) applied Artificial Neural Networking (ANN) using MATLAB for 14 parameters of groundwater quality in a part of Hindon basin India. The ANN analysis was correlated with the maximum likelihood analysis using image processing software. It was found out that properties of river water hardly affected the properties of ground water in this area. Though a non-linear relationship existed and may be validated in each case, they might not correspond one to one. It is also important to note that though the models tested above were good to find a relationship between various quality parameters in river water, the same were not found suitable to provide the fruitful results for ground water.

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Chapter 4
Climate Change and Climate Models

Abstract The uncontrolled extraction of natural resources, non-moderated growth in industrial activities, destruction of natural forest and water bodies followed by the rising demand for water and energy from the ever growing population to sustain their livelihood as well as luxury and the recent technological advancements has increased the stress on water resources of most of the countries in the World. The use of fossil fuel has increased many fold compared to the earlier decades and as a result amount of green house gas in the atmosphere has increased. The greenhouse gases or GHG is responsible for raising atmospheric temperature. It also prevents the escape of heat from the earth crust. Thus increase in GHG concentration can cause global warming or cooling. The warming or cooling of atmosphere will certainly influence the regular climatic pattern. The change in climatic pattern will induce abnormality in the precipitation as well as evaporation patterns of any region which will again impose variations in the available volumes of freshwater. To predict the future climate and also to analyze the impact of climate change on different natural resources some models have been prepared which are classified under Global Circulation Model (GCM) and Regional Circulation Model (RCM). The former can predict global and the latter can predict the regional climate. Intergovernmental Panel of Climate Change (IPCC) utilizes this model and some scenarios to predict the impact of climate change for different probable situations into which the situation of the future earth may be evolved. The IPCC has predicted the impact for all over the World and has published a report known as Fourth Assessment Report.

Keywords Climate change · PRECIS · IPCC · Global circulation model (GCM) · Regional circulation model (RCM)

4.1 Climate Change

Climate change poses threats to the region's native peoples, infrastructure, agriculture, and recreational activities. It will likely place additional stress on infrastructure and the economy. Climate change is also affecting wildlife—for instance,

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Arctic polar bears are at risk of losing their environment; the Golden Toad has gone extinct; and the most adaptable species are evolving into new versions capable of withstanding warmer water.

Climate change mitigation policies affect countries' economic growth, saving and investment levels, capital flows, and exchange rates. Climate change can increase the vulnerability of a resource, ecosystem, or human community, causing a proposed action to result in consequences that are more damaging than prior experience with environmental impacts analysis might indicate. Climate change would both affect the extent of areas prone to desertification and the severity of desertification in existing drylands.

Climate change could further exacerbate existing problems over water scarcity in many Mediterranean countries and cause a decline in water quality through increased concentrations of pollutants, salinisation and increased salt water intrusion in coastal aquifers. Climate change projected by the IPCC 2013 report under the business-as-usual scenario projects warming in the next 80–90 years to be bigger than the Paleocene/Eocene Thermal Maximum extinction event 56 million years ago, only changes today are happening 100 times faster than then.

As climate change worsens, dangerous weather events are becoming more frequent or severe in the United States and around the globe. As climate change continues to threaten vulnerable Australians, through heatwaves, extreme weather events and droughts. Future climate change and the associated environmental changes would directly threaten natural ecosystems in the Mediterranean region, including biosphere reserves and wetland sites of recognised international importance.

4.1.1 Causes

Most climate scientists agree the main cause of the current global warming trend is human expansion of the "greenhouse effect" warming that results when the atmosphere traps heat radiating from Earth toward space.

Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to changes in temperature are described as "forcing" climate change. Gases, such as water vapor, which respond physically or chemically to changes in temperature are seen as "feedbacks."

Gases that contribute to the greenhouse effect include:

Water vapor The most abundant greenhouse gas, but importantly, it acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect.

Carbon dioxide (CO_2) A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO_2 concentration by a third since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change.

Methane A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule-for-molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere.

Nitrous oxide A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Chlorofluorocarbons (*CFCs*) Synthetic compounds of entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also greenhouse gases.

4.1.2 Impacts

National and global security can be assessed in many ways but one underlying factor for all humanity is access to reliable sources of water for drinking, sanitation, food production and manufacturing industry. In many parts of the world, population growth and an escalating demand for water already threaten the sustainable management of available water supplies. Global warming, climate change and rising sea level are expected to intensify the resource sustainability issue in many water-stressed regions of the world by reducing the annual supply of renewable fresh water and promoting the intrusion of saline water into aquifers along sea coasts, where 50 % of the global population reside.

Pro-active resource management decisions are required, but such efforts would be futile unless reliable predictions can be made about the impact of the changing global conditions on the water cycle and the quality and availability of critical water reserves. Addressing this wide spectrum of issues, a team of expert authors discusses here the impacts of climate change on the global water resources, the long-term resource management goals at global and local scales, the data requirements and the scientific and technical advances necessary to mitigate the associated impacts.

1. Quantity, variability, timing, form, and intensity of precipitation
2. Rise in annual-mean temperatures
3. Increased evaporation rates
4. Water availability
5. Shifting in Cropping practice
6. Shift in stream hydrographs

7. Water quality
8. Rising sea levels
9. Water Allocation Conflicts

4.1.2.1 Quantity, Variability, Timing, Form, and Intensity of Precipitation

Climate change will affect water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation. This paper provides an overview of the projected physical and economic effects of climate change on water resources in North America (with a focus on water shortages), and a brief discussion of potential means to mitigate adverse consequences. More detailed information on this complex topic may be found in Adams and Peck (forthcoming) and in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4).

4.1.2.2 Rise in Annual-Mean Temperatures

Models of climate change (GCMs) predict U.S. annual-mean temperatures to generally rise by 2–3 °C over the next 100 years, with greater increases in northern regions (5 °C), and northern Alaska (10 °C). Numerous other climatic effects are also expected. For example, U.S. precipitation, which increased by 5–10 % over the 20th century, is predicted to continue to increase overall. More specifically, an ensemble of GCMs predicts a 20 % increase for northern North America, a 15 % increase in winter precipitation for northwestern regions, and a general increase in winter precipitation for central and eastern regions. Despite predictions of increased precipitation in most regions, net decreases in water availability are expected in those areas, due to offsetting increases in evaporation. A 20 % decrease in summer precipitation, for example, is projected for southwestern regions, and a general decrease in summer precipitation is projected for southern areas. Although projected regional impacts of climate change are highly variable between models, the above impacts are consistent across models.

4.1.2.3 Increased Evaporation Rates

Additional effects of global climate change that have important implications for water resources include increased evaporation rates, a higher proportion of precipitation received as rain, rather than snow, earlier and shorter runoff seasons, increased water temperatures, and decreased water quality in both inland and coastal areas. The physical and economic consequences of each of these effects are discussed below.

Increased evaporation rates are expected to reduce water supplies in many regions. The greatest deficits are expected to occur in the summer, leading to decreased soil moisture levels and more frequent and severe agricultural drought. More frequent and severe droughts arising from climate change will have serious management implications for water resource users. Agricultural producers and urban areas are particularly vulnerable, as evidenced by recent prolonged droughts in the western and southern United States, which are estimated to have caused over $6 billion in damages to the agricultural and municipal sectors. Such droughts also impose costs in terms of wildfires, both in terms of control costs and lost timber and related resources.

Water users will eventually adapt to more frequent and severe droughts, in part by shifting limited water supplies towards higher-value uses. Such shifts could be from low- to high-value crops, or from agricultural and industrial to environmental and municipal uses. A period of delay is likely, however, because gradual changes in the frequency and severity of drought will be difficult to distinguish from normal inter-annual variations in precipitation. Economic losses will be larger during this period of delay, as compared to a world with instantaneous adjustment, but pre-emptive adaptation could also be costly given the uncertainty surrounding future climate.

4.1.2.4 Water Availability

If the runoff season occurs primarily in winter and early spring, rather than late spring and summer, water availability for summer-irrigated crops will decline, and water shortages will occur earlier in the growing season, particularly in watersheds that lack large reservoirs. Agricultural producers, in response to reduced water supplies and crop yields, will adjust their crop mix. Producers in irrigated regions might reduce total planted acreage, or deficit-irrigate more acres, to concentrate limited water supplies on their most valuable crops (e.g. onions and potatoes, rather than wheat and alfalfa). Producers in rain-fed regions might shift to crop species and varieties with shorter growing season requirements or greater drought tolerance, such as winter grains.

4.1.2.5 Shifting in Cropping Practice

Cropping practices are likely to shift as well, perhaps towards reduced- or no-till technologies, which enhance water infiltration and conserve soil moisture, or towards irrigation technologies that are more efficient at the farm level (although not necessarily at the basin level). Producers may begin to supplement dwindling surface water supplies with groundwater resources, a response that has already been observed in many drought-stricken areas. These adjustments will mitigate a portion of private economic losses. They will also affect environmental quality, although the expected direction is more difficult to predict.

4.1.2.6 Shift in Stream Hydrographs

A shift in stream hydrographs to more winter flow may also disrupt the life cycle of cold water fish species, such as salmon, which depend on late spring flows to "flush" young salmon to the ocean, and on summer flows to moderate water temperatures. Unless winter runoff is captured and stored for late spring or summer use, fewer salmon smolt will survive migration and more frequent fish kills will occur from lethal stream water temperatures. Such environmental impacts will intensify debates about consumptive versus in stream water uses, such as those ongoing in the Klamath and Platte River Basins.

4.1.2.7 Water Quality

Climate change is expected to affect water quality in both inland and coastal areas. Specifically, precipitation is expected to occur more frequently via high-intensity rainfall events, causing increased runoff and erosion. More sediments and chemical runoff will therefore be transported into streams and groundwater systems, impairing water quality. Water quality may be further impaired if decreases in water supply cause nutrients and contaminants to become more concentrated. Rising air and water temperatures will also impact water quality by increasing primary production, organic matter decomposition, and nutrient cycling rates in lakes and streams, resulting in lower dissolved oxygen levels. Lakes and wetlands associated with return flows from irrigated agriculture are of particular concern. This suite of water quality effects will increase the number of water bodies in violation of today's water quality standards, worsen the quality of water bodies that are currently in violation, and ultimately increase the cost of meeting current water quality goals for both consumptive and environmental purposes.

4.1.2.8 Rising Sea Levels

Rising sea levels could also reduce water quality and availability in coastal areas. Recent projections of sea-level rise by the end of the 21st century range from 19 to 58 cm. A more dramatic increase in sea-level, on the order of meters rather than centimeters, is possible, but most scientists consider it a low probability risk. For example, complete melting of the Greenland Ice Sheet or West Antarctic Ice Sheet would trigger such a large rise. Rising sea levels could affect groundwater quality directly via saltwater intrusion. Radical changes to the freshwater hydrology of coastal areas, caused by saltwater intrusion, would threaten many coastal regions' freshwater supplies.

Rising sea levels could also affect water availability in coastal areas indirectly by causing water tables in groundwater aquifers to rise, which could increase surface runoff at the expense of aquifer recharge. Water shortages will cause the price of water to rise, through monthly water bills or one-time connection fees for new homes and businesses. A sufficiently large price increase could affect the extent and pattern of urban growth throughout the United States. Costly water supply projects, such as desalination plants, pipelines, and dams will also become more economically attractive.

4.1.2.9 Water Allocation Conflicts

One final and important effect of the water resource impacts discussed above is the potential for more frequent and intense interstate and international water allocation conflicts. Water markets have the potential to prevent or diffuse such conflicts; however, the assignment of water rights to establish the market can create more conflict than it diffuses.

4.2 Climate Models

In general terms, a climate model could be defined as a mathematical representation of the climate system based on physical, biological and chemical principles. The equations derived from these laws are so complex that they must be solved numerically.

4.2.1 Definition

As a consequence, climate models provide a solution which is discrete in space and time, meaning that the results obtained represent averages over regions, whose size depends on model resolution, and for specific times. For instance, some models provide only globally or zonally averaged values while others have a numerical grid whose spatial resolution could be less than 100 km. The time step could be between minutes and several years, depending on the process studied.

4.2.2 Types

Global climate models (GCMs) are comprised of fundamental concepts (laws) and parameterization of physical, biological, and chemical components of the climate system. These concepts and parameterization are expressed as mathematical equations, averaged over time and grid volumes.

A global climate model needs to include a number of component models to represent the oceans, atmosphere, land, and continental ice and the fluxes between each other. Weather models represent a subset of climate models, in which the basic framework of all scales of weather models is presented.

"All numerical models of the atmosphere are based upon the same set of governing equations, describing a number of known physical principles. Where numerical models differ, is how the individual equations are solved; what approximations and assumptions are made and how one represents the physical processes in the physical parameterization in the atmosphere, for example radiation, convection and precipitation to name a few, often occur at a scale too small to be directly resolved by the numerical model and thus need to be parameterized, i.e., described not by known physical principles, but in an empirical way."

4.2.2.1 General Circulation Model

Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis, thus fulfilling criterion 2.

GCMs depict the climate using a three dimensional grid over the globe (see below), typically having a horizontal resolution of between 250 and 600 km, 10–20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans. Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments, hence only partially fulfilling criterion 3.

Examples

HadCM3

This was the standard coupled model of the Met Office until a few years ago, and is still actively used for climate change research. A future release of this model is planned by climateprediction.net. Read more about this model on the Met Office website.

Atmosphere: 2.5 × 3.75 degrees lat-lon resolution, 19 vertical levels (known as N48; comparable resolution to ~T42), 30 min timestep for dynamics, 3 h for radiative transfer.

Ocean: 1.25 × 1.25 degrees lat-lon resolution, 20 vertical levels, 1 h timestep.

Sulphur and carbon cycles, dynamic vegetation etc. are optional.

HadCM3L

HadCM3 with a reduced resolution ocean. This was used for the BBC Climate Change experiment and the completed Geo-engineering experiment. The climate prediction.net version uses two kinds of modified ocean topography, both with no Iceland.

Atmosphere: same as HadCM3.

Ocean: 2.5 × 3.75 degrees, 20 levels, 1 h time step.

This model is not used with any current experiments. It has been replaced by the newer HadCM3S.

HadCM3N

This is another version of HadCM3 which runs for 40 years and is not flux-adjusted. It is used for the RAPID-CHAAOS and RAPID-RAPIT experiments.

4.2.2.2 Regional Circulation Model

A key limitation of Global Climate Models (GCMs) is the fairly coarse horizontal resolution. For the practical planning of local issues such as water resources or flood defences, countries require information on a much more local scale than GCMs are able to provide. Regional models provide one solution to this problem.

There are three possible solutions to the problem of course resolution in GCMs:

The GCM can be run with a finer resolution. As the model would then take much longer to complete a simulation, you will either need a very powerful computer or to run the simulation for a much shorter period (e.g. 5 years).

Use statistical techniques to ‘downscale’ the coarse, GCM results to local detail (read more about this here). These techniques assume that the relationship between large scale climate variables (e.g. grid box rainfall and pressure) and the actual rainfall measured at one particular rain gauge will always be the same. So, if that relationship is known for current climate, the GCM projections of future climate can be used to predict how the rainfall measured at that rain gauge will change in the future.

Embed a Regional Climate Model (RCM) in the GCM.

Regional Climate Models (RCMs) work by increasing the resolution of the GCM in a small, limited area of interest. An RCM might cover an area the size of western Europe, or southern Africa—typically 5000 km × 5000 km. The full GCM determines the very large scale effects of changing greenhouse gas concentrations and volcanic eruptions on global climate. The climate calculated by the GCM is used as input at the edges of the RCM for factors such as temperature and wind. RCMs can then resolve the local impacts given small scale information about orography (land height) and land use, giving weather and climate information at resolutions as fine as 50 or 25 km.

A regional climate model (RCM) is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a global general circulation model (GCM). GCMs are typically run with horizontal scales of 300 km. RCMs can resolve features down to 50 km or less. This makes for a more accurate representation of many surface features, such as complex mountain topographies and coastlines. It also allows small islands and peninsulas to be represented realistically, whereas in a global model their size (relative to the model grid box) would mean their climate would be that of the surrounding ocean.

RCMs are full climate models, and as such are physically based. They represent most if not all of the processes, interactions and feedbacks between climate system components represented in GCMs. They produce a comprehensive set of output data over the model domain. There are three types of technique for obtaining regional climate change projections: statistical, dynamical and hybrid (statistical-dynamical) techniques. RCMs fall into the dynamical category (Climate Prediction 2014).

Examples

PRECIS

The PRECIS climate model (stands for “Providing REgional Climates for Impacts Studies”) is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described. Boundary conditions are required at the limits of the model’s domain to provide the meteorological forcing for the RCM. Information about all the climate elements as they evolve through being modified by the processes 22 Generating high resolution climate change scenarios using PRECIS represented in the model is produced.

4.2.3 Intergovernmental Panel on Climate Change

Scientists have high confidence that global temperatures will continue to rise for decades to come, largely due to greenhouse gasses produced by human activities. The Intergovernmental Panel on Climate Change (IPCC), which includes more than 1300 scientists from the United States and other countries, forecasts a temperature rise of 2.5–10 °F over the next century.

According to the IPCC, the extent of climate change effects on individual regions will vary over time and with the ability of different societal and environmental systems to mitigate or adapt to change.

The IPCC predicts that increases in global mean temperature of less than 1.8–5.4 °F (1–3 °C) above 1990 levels will produce beneficial impacts in some regions and harmful ones in others. Net annual costs will increase over time as global temperatures increase.

"Taken as a whole," the IPCC states, "the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time."

Below are some of the regional impacts of global change forecast by the IPCC:

North America: Decreasing snowpack in the western mountains; 5–20 % increase in yields of rain-fed agriculture in some regions; increased frequency, intensity and duration of heat waves in cities that currently experience them.

Latin America: Gradual replacement of tropical forest by Savannah in eastern Amazonia; risk of significant biodiversity loss through species extinction in many tropical areas; significant changes in water availability for human consumption, agriculture and energy generation.

Europe: Increased risk of inland flash floods; more frequent coastal flooding and increased erosion from storms and sea level rise; glacial retreat in mountainous areas; reduced snow cover and winter tourism; extensive species losses; reductions of crop productivity in southern Europe.

Africa: By 2020, between 75 and 250 million people are projected to be exposed to increased water stress; yields from rain-fed agriculture could be reduced by up to 50 % in some regions by 2020; agricultural production, including access to food, may be severely compromised.

Asia: Freshwater availability projected to decrease in Central, South, East and Southeast Asia by the 2050s; coastal areas will be at risk due to increased flooding; death rate from disease associated with floods and droughts expected to rise in some regions (NASA 2014).

4.2.3.1 Scenario Creations

The 40 scenarios, 35 of which are fully quantified, are based on four different narrative storylines and associated scenario families. Each storyline describes a different world evolving through the 21st century, and each may lead to quite different GHG emissions trajectories (IPCC 2000).

A1: A future world of very rapid economic growth, global population that peaks mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. Major underlying themes are economic and cultural convergence and capacity-building, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system: fossil-intensive (A1FI), nonfossil energy sources (A1T), and a balance across all sources (A1B).

A2: A differentiated world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in continuously increasing population. Economic development is primarily regionally orientated, and per capita economic growth and technological change are more fragmented and slower than other story lines.

B1: A convergent world with rapid change in economic structures toward a service and information economy, reductions in material intensity, and introduction of clean technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improving equity, but without additional climate change policies.

B2: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. This is a world with continuously increasing global population at a lower rate than in scenario A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 story lines. Although this scenario also is orientated toward environmental protection and social equity, it focuses on the local and regional levels.

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Chapter 5
Detail Methodology

Abstract The present study utilized the MCDM and ANN technologies to estimate the severity of water shortage in different locations. The MCDM methods like AHP and FLDM method was utilized where the results of both were ensemble to find the priority values of the considered input parameters of the indicator. The indicator was provided with cognitive ability by inducting the ANN model for estimation of final value of the index. The index was tested for Eighteen scenarios in total. Three study areas having different level of urban population and six various climate change scenarios are produced and the index was estimated for each of the scenarios. The performance metrics of the model and sensitivity analysis of the index was also carried out.

Keywords Multi criteria decision making · Artificial neural network · Index

5.1 MCDM

The objective of the framework is to estimate the severity of water shortage in different locations due to change in urbanization and climatic pattern. The urbanization and climate change on the other hand depends upon various factors:

$$\mathrm{WS} = \mathrm{f}(\mathrm{u}, \mathrm{c}), \quad \text{where}\, \mathrm{u} = \mathrm{f}(\mathrm{a}) \text{ and } \mathrm{c} = \mathrm{f}(\mathrm{b}). \tag{5.1}$$

where u and c are dependent function of urbanization and climate change and u and c are again dependent on a and b respectively. The a and b parameters are independent of any variable but represents the factors which effects the change in climate and urban density.

The a and b parameters can be identified by an extensive literature survey and discussions with the experts in related field.

As MCDM methods are widely popular to provide solution to the present type of multi-criteria decision making problems. That is why to assign weights of importance various other factors has to be conceptualized first. The present investigation

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used their strengths to find the difference of influence or importance of each of the a and b parameters.

In the present study the weight of importance were determined by Analytical Hierarchy Process (AHP) and Fuzzy Logic Decision Making (FLDM) as both the methods are applicable and considers both qualitative and quantitative variables. Thus AHP and FLDM method was adopted to find the weight of importance for each of the parameters. The steps below provide the methodology adopted to determine the weights of importance for each of the a and b parameters by MCDM methods.

Although a and b parameters can influence U and C separately but as WS is a dependent function of U and C all the a and b parameters are compared in a single pair-wise comparison matrix.

5.1.1 Selection of Criteria

In the present study the weights of importance of the a and b parameters are required to be estimated. So, all these parameters are considered as alternatives. To find the weights of importance some criteria has to be identified with respect to which the alternatives will be compared and the difference in importance can be determined. In this regard the following factors are considered as Criteria.

(i) *Expert Survey* A survey was carried out within experts of related fields where participants were asked to suggest about the a and b parameters. The participants were also requested to provide their estimate about the most and least important parameter in this aspect. According to the response received from the experts a score was calculated and assigned to the factors according to Eq. 5.2.

If 'A' is number of experts which mentioned the parameter and 'e' be the number of expert which has referred it as most important parameter and e′ be the number of expert who have mentioned the parameter as not at all important then,

$$SE = (Ax(e/e'))./At \tag{5.2}$$

where SE is the score assigned to the parameter and At is the total number of experts consulted regarding the present problem.

The score was then normalized and according to the score the top ten parameters were determined.

(ii) *Literatures Review* The literatures were also surveyed to find the citation of the parameters in related studies. If the number of literatures which mentioned the parameter is l and the total number of literatures surveyed be L then the score, SL, is calculated by Eq. 5.3.

$$SL = (l/L) \tag{5.3}$$

This score was also normalized and the parameters are ranked accordingly in a descending manner.

(iii) *Stakeholders Survey* The stake holders or the people who are dependent on the water resources of a region for sustenance of their socio-economic status a survey were conducted among some local people of different regions about the impact of the considered parameters on the intensity of water shortage.

After the survey the importance given to the considered parameter by the local people was utilized to rank the parameters according to their importance. The score which helped to decide the rank of a certain parameters is given by Eq. 5.4.

$$\mathrm{Ss} = (\mathrm{s}/\mathrm{S}) \tag{5.4}$$

where s is total number of local participants who have given importance to the parameter and S is the total number of participants of the survey.

(iv) *Sponsor's Preference* A allocators of government fund or industrial units or some non-governmental organizations are involved in funding projects for sustenance of the water resources in different regions of the World. The feedback from these people is also included. Equation 5.5 was utilized to estimate the score of the parameters with respect to Sponsor's preference.

$$\mathrm{SSsp} = (\mathrm{p}/\mathrm{Ssp}) \tag{5.5}$$

where SSsp is the score to be assigned, p and Ssp is respectively total number of sponsors who have given highest importance to the parameter and number of sponsors discussed for the survey.

(v) *Data Availability* The parameters were also compared based on the data availability. There are three kinds of data that can be retrieved which represents the status of the parameter: Primary, Secondary and Calculative. Primary data is the dataset which are prepared based on the sample survey.

Secondary data are historical data stored in databases and various reports. Calculative datasets are not directly/readily available and has to be calculated based on some premade equations. The score assigned to the parameters with respect availability of data is given in Eq. 5.6.

$$\mathrm{Sda} = (\mathrm{aPri} + \mathrm{bSec} + \mathrm{cCal})/(\mathrm{a} + \mathrm{b} + \mathrm{c}) \tag{5.6}$$

where a, b, c are any constants less than 1 and $(a + b + c) = 1$

Pri, Sec and Cal are the number of primary, secondary and calculative data sources available for the parameter. The score is normalized and based on the normalized score the parameters are arranged from most to least important factors.

According to the AHP and FLDM method the criteria are first compared with each other to find the difference of importance between them. Thus a (5×5) matrix was formulated and each of the criteria is compared with the other criteria with respect to its importance over the other parameter.

If total number of experts surveyed be At, total number of literatures surveyed be L, the total number of stakeholders and sponsors surveyed be S and Sp respectively and the total number of sources for retrieval of dataset of related parameters be D, then

$$\text{for Expert Survey} = E/(At + L + S + Sp + D) \quad (5.7)$$

$$\text{for Literatures Survey} = L/(At + L + S + Sp + D) \quad (5.8)$$

$$\text{for Stakeholders Survey} = S/(At + L + S + Sp + D) \quad (5.9)$$

$$\text{Sc for Sponsor's Preference} = Sp/(At + L + S + Sp + D) \quad (5.10)$$

$$\text{Sc for Data Availability} = D/(At + L + S + Sp + D) \quad (5.11)$$

where Sc is the score assigned to the criteria.

The score of the criteria are then normalized and ranked in a descending manner.

The rank of the criteria is utilized to find the difference of importance between the criteria in the comparison matrix of both AHP and FLDM.

5.1.2 Selection of Alternative

The eight different a and b parameters were selected as the alternatives. All the parameters are measurable, independent of each other, real and is a direct function of the decision objective.

5.1.3 Aggregation Methods

In the present investigation AHP and FDM is utilized for identifying the weight of importance of the parameter as both of these methods can consider both quality and quantitative parameters in the process of decision making. A 5 × 5 matrix of criteria is developed to find the weights of the criteria. The comparative rating was given as per Saaty scale for the AHP method and Zadeh scale for the FLDM method.

If C is the Criteria matrix and A is the alternative matrix then,

$$C = \{m, m\} \quad (5.12)$$

where,

$$m = \{At, L, S, Ssp, D\} \quad (5.13)$$

The scale proposed by Saaty is used to rate the pair-wise importance of each of the criteria.

Again the alternatives are compared with each other based on their importance over each other with respect to each of the criteria and thus,

$$A = \{a, b{:}a, b\} \quad (5.14)$$

where,

a = Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd), Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da), Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di), Percentage Impervious Area (last 10 years) (A), Annual Average Area of Canopy (Ac) and Frequency of Troughs in Annual Water Quality Index curve (WQI)

b = Frequency of Troughs in Annual Hyetograph (P) and Frequency of Peak in Annual Hydrograph (Q)

The importance was determined by the rank achieved by the alternatives with respect to the criteria. The rating for depicting importance was given according to the Satty scale.

The geometric sum of each of the rows are calculated and normalized to find the weight of importance of the alternatives with respect to the criteria. Thus for each criteria, alternatives will have separate weight of importance. Ultimately a 5 × 8 matrix was drawn where weight of criteria is multiplied by the weight of alternatives for that criterion and averaged to find the weight of importance of the alternatives.

In case of FLDM, the pair-wise rating was performed with the help of littoral fuzzy ratings. The fuzzy rating was then converted to crisp rating by the application of theory of maximization. The weight of importance of the criteria and alternative in case of FLDM is estimated by Eq. 5.15.

$$W = \mathrm{Norm}\{\mathrm{Avg}(r/R)\} \quad (5.15)$$

where W is the weightage of importance, r is the score of the littoral rating of the row alternative with respect to the column alternative and R is the maximum score of the row.

Avg indicates the average value of the r/R of a row. The normalization of the average value of each row is taken as weight of importance of the alternatives or criteria represented by the row.

All the other steps for comparing the criteria, alternative and resultant super matrix is similar to the AHP method.

5.1.4 Determination of Priority Values

The priority value was determined with the help of the average of the results from AHP and FLDM method.

5.2 Water Limitation Index

After the weight of importance is determined an index was developed with the help of the weight and the magnitude of the a and b parameters. The weighted average of all the parameters is proposed as the index for representation of the vulnerability of water resources or severity of the water shortage problem. The function is represented in Eq. 5.16.

$$V = \frac{\sum_{i=1}^{9} w_i \times D_i}{\sum_{i=1}^{9} w_i} \tag{5.16}$$

where V is the Water Limitation index, w_i is the weightage of importance of the a and b parameters as determined in the previous section.

5.3 ANN

The present study aims to develop index for representation of the impact of climate change and urbanization on availability of water resources.

In this regard some algorithms have to be prepared so that V can be automatically calculated once the values of the a and b parameters of the area of interest is given as input. Due to the popularity of ANN, in mapping non-linearity and unknown relationships the said algorithm is applied to estimate the Water Limitation Index (V). Another reason for applying ANN is to remove the requirement of repeated application of the MCDM methods once a new alternative is added. In the present study the ANN models were applied to predict the decision for the new alternative based on the existing knowledge that was gained from the available set of data.

As only normalized data is fed to the model the impact due to the difference of scale will be absent and thus the same model can be used for different locations.

5.3.1 Input and Output

The input to the model was selected to be:

As *a* parameters:
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd),
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da),
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di),

Percentage Impervious Area (last 10 years) (A),
Annual Average Area of Canopy (Ac) and
Frequency of Troughs in Annual Water Quality Index curve (WQI)
As *b* parameters
Frequency of Troughs in Annual Hyetograph (P) and
Frequency of Peak in Annual Hydrograph (Q)
The *output of the model* is the Water Limitation Index or V.

5.3.2 Topology

The number of hidden layers is responsible for quick learning of the problem but also increase the load on the computational infrastructure. That is why, selection of an optimal number of hidden layers is important for efficient performance of the neural network models and in the present study the said task was performed with the help of genetic algorithms where 50 generations were produced from 40 populations. The cross over rate was fixed at 0.8 whereas the mutation rate was controlled within 0.2.

5.3.3 Training

In development of the ANN model a training dataset is required to be provided. The dataset for training is the normalized representation of the magnitudes of the input variables in a specific location. That is why if different situations of the normalized output of the input variables are fed to the index and then the interrelationship between the input and output variable can be mapped the neural model then an universally acceptable modelling framework can be prepared which can be applied to any location of the World for the analysis of the severity of water shortage.

Thus the neural model is trained with a normalized set of data representing different situations of the input variables and the corresponding results of the situation which are calculated by the index.

A combinatorial search algorithm was used to train the ANN model and the architectural pattern of polynomial neural networks was followed to perform the iterations for identifying the optimal weights of the input variables.

5.3.4 Performance Metrics

The following performance metrics are analysed to find the accuracy of the model:

- Maximum Negative Error

- Max Positive Error
- Mean Absolute Error
- Root Mean Square Error
- Standard Deviation of Residuals
- Correlation Coefficients

5.4 Sensitivity Analysis

The sensitivity analysis was performed with the help of Multiple Input One output Tornado method developed by SensIt Limited. The range for the input variables were varied between 0 and 1. The impact of each input is then observed on the output and the results were compared with the weights of the variables found from the MCDM analysis.

5.5 Scenario Analysis

Three locations were selected having different level of population density. All the three locations are situated beside the river. The name of the locations and river is given below:

1. Farakka Township on River Ganges
2. Mahi River Dam on Mahi River
3. Vaigai Dam in River Periyar

5.5.1 Farakka Township

The Farakka Barrage diverts water from the Ganga to the Bhagirathi distributary (which becomes the Hooghly downstream) via a feeder canal that is 41 km (25.5 miles) long and 300 m (0.2 miles) wide and has locked gates (Figs. 5.1, 5.2 and 5.3).

The River Ganga (Ganges) originates at the Gangotri Glacier of the Uttaranchal Himalayas at an altitude of about 5 miles. It flows through the plains of North India, breaks into its first distributary, the Hooghly, 11 miles before it enters Bangladesh as the Padma River. The Padma eventually joins with the Jamuna (of the Brahmaputra) and Meghna (of the Barak) in Bangladesh and branches into an intricate net of distributaries, all of which finally pour into the Bay of Bengal. The Ganga has a length of over 1,620 miles and drains an area of nearly 405,600 square miles in northern India, Bangladesh, Nepal, and southern Tibet.

Fig. 5.1 Figure showing the location of Farakka Township

Fig. 5.2 Figure showing the location of Mahi River Dam on River Mahi

Rivers are a dominant force behind Bangladeshi cultural and economic identity. Roughly 60 % of the Bangladeshi population are farmers, who depend heavily on cycles of flow and siltation. Fish constitute as high as 80 % of the Bangladeshi diet. The world's largest delta formation, the mighty mangrove forests of the Sundarbans, lies mostly in Bangladesh.

In addition to the three main rivers Padma, Meghna and Jamuna, about 55 smaller rivers and tributaries enter Bangladesh from India, and three from Myanmar. 94 % of Bangladesh's aboveground freshwater supply thus originates from outside its political boundaries. As the lowermost riparian state of the Ganga-Brahmaputra-Meghna basin, Bangladesh is most vulnerable to ecological degradation and water withdrawal upstream. Total Area of the Farakka township is 3.7 km^2, Population Density is 5,439.5 inh/km^2 [2011]—Change in 2011 from 2001 is −0.91 %/year.

Fig. 5.3 Figure showing the location of Vaigai Dam on River Vaigai

5.5.2 Mahi Dam

Mahi River originates from Vindhyachal Hills, Madhyapradesh and meets in Bay of Khambhat. Its total length is 583 km and catchment area is 34,842 km^2. Bhadar is right bank tributary and Panam, Kun and Goma are left bank tributaries of Mahi river.

On Mahi river Kadana dam is situated at 25 km distance. Its catchment area is 25,520 km^2. Wanakbori weir is situated at 102 km on Mahi river having 30,665 km^2 catchment area.

There is Bhadar dam on river Bhadar at 19 km distance having 407 km^2 catchment area.

Hadaf and Koliyari are two subtributaries of Panam river. Panam dam is located on Panam river at Panam at distance of 83 km having catchment area 2312 km^2 Kabutri and Wankadi are subtributaries of Hadaf river. Hadaf dam is situated on Hadaf river having 508 km^2 catchment area. Umaria dam is also located on Hadaf river at 13 km distance having 73 km^2 catchment area.

Karad dam is situated on Karad river at 13 km distance having 130 km^2 catchment area. Goma dam is located on Goma river at 120 km distance having 175 km catchment area.

5.5.3 Vaigai Dam

Vaigai Dam on River Vaigai which originated from the longest Periyar River of Kerala—which empties at Periyar Lake—wherefrom water is being let out into Vaigai River. Over the centuries, the population explosion to manifold proportions, had it that Dams were to be constructed across the rivers, to regulate the flow and save water in reservoirs for irrigation and power generation purposes.

Unlike the ancient times, where Rivers were flowing in their natural course, these man-made developments changed the entire scenario. Border disputes and sharing of river waters between the riparian States have become political problems of today. The Mullai-Periyar Dam issue is a heated up dispute between Kerala State and Tamil Nadu. Result is Vaigai River has been left "high and dry" in the true sense of the phrase.

Tamilnadu built the Vaigai Dam, across the Vaigai River to feed irrigation waters to many areas like Theni, Kambam etc., which are on the upper portions of the River than Madurai City. This is also another reason why Vaigai River, which flows in the centre of present Madurai City, has gone dry.

All in all Vaigai River gets water, if only the Dams are full during rainy season and otherwise for many months in a year the river looks pathetic. Worse still if the monsoon fails and the Dams—Periyar and Vaigai—do not get any water at all.

The annual Chithirai Thirunall Festival, (during the hot summer month of April) conducted to enact the divine marriage of Meenakshi Amman with Sundareswarar, during which time the Kallazahar (Lord Vishnu) is brought to take a holy-dip in Vaigai River, is also getting jeopardized because of this. This is a famous festival at Madurai, when hundreds of thousands of people from various parts of not only Tamilnadu but also from other States converge at Madurai.

To tide over the crisis of acute water shortage, the authorities select a specific place in the middle of the river and pour water brought through hundreds of vehicles, to make an artificial pool. It is here Azhagar dips into Vaigai River—not to forego a religious ritual of centuries old!

Chapter 6
Results and Discussions

Abstract The present investigation attempted to represent the severity off water scarcity with the help of an indicator. As existing indexes have drawbacks like they do not considers the temporal variability of the input parameters, not includes quality of water as a parameter and also the influence of all the parameters are taken as equal. To compensate the above drawbacks of the existing water availability indicators and to estimate the situation of water availability in an optimal manner a new indicator was developed. The input parameter of the index was selected based on literature review followed by expert and stakeholder survey. The temporal variability was also included by taking the amplitude values of variation curves with respect time of the selected parameters. The quality parameter was also introduced with the help of Water Quality Index (WQI). Lastly a new MCDM method was created to assign priority values to the input parameters based on their importance in influencing the level of water scarcity. The method is new as it combines the output from AHP and FLDM to determine the weights of importance for the parameters. Moreover a cognitive ability was introduced to the index by applying ANN for finally estimating the value of the indicator. According to the results, the Frequency of Troughs in Annual Hyetograph (P) and Percentage Impervious Area (A) was found to be respectively the highest and lowest important parameter among the eight input parameters considered in the study. If criteria by which the importance of the alternatives are compared it can be said that Literature Survey and Data Availability was found to be most and Sponsor's Preference the least important criteria among the five criteria considered in the study. The accuracy of the ANN model was found to be above 99.95 % and the number of hidden layer and type of activation function was decided to be respectively three nodes in one layer and logistic function. The sensitivity analysis of the model was also performed and found to be coherent with the weights of importance of the parameters as determined in the MCDM step. The scenario wise prediction of the index value was also carried out. Based on the results it can be said that in industrially sensitive A2 the location having high level of urban population will always face the higher level of water scarcity. But in case of B2 such clear conclusions can not be made.

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Keywords Water limitation · Water quality index · AHP · FLDM · AHP-FLDM hybrid · Combinatorial ANN

6.1 Results from MCDM Applications

In the MCDM step five types of criteria were selected and compared with the help of the score as found from Eqs. 5.7–5.11.

According to the score of each of the criteria, Literature Survey and Data Availability was found to be most and Sponsor's Preference was the least important criteria among the five criteria considered in the present study (Table 6.1). The weights of the alternatives were found by comparing each other with respect to each of the criteria.

The result of the comparison by AHP and FDM is depicted in Table 6.2. According to the table, Frequency of Troughs in Annual Hyetograph (P) and Percentage Impervious Area (A) was found to be the most and least important parameters respectively among the eight factors considered. In both AHP and FDM method the same parameters was found to be the most and least preferred alternative.

6.2 Results from ANN Applications

The ANN model was developed to predict the Water Limitation Index (V) from different scenarios of the selected factors. The model was trained with feed forward polynomial neural networks. A combinatorial search to find the optimal weight was also carried out simultaneously. Figure 6.1 shows the comparison between actual data, model predicted data during the training process and the predicted data from the model. According to this figure the model has more than 99.95 % of accuracy level. The residual errors as depicted in Fig. 6.2 also seconded the satisfactory learning of the problem by the model. Most of the residuals lie in between the 2 times the standard deviation of the dataset which also shows the reliability of the developed model. From the frequency distribution of errors it can be observed that

Table 6.1 Table showing the criteria considered to compare the factors

Criteria	Total number	Total number of sources	Score	Rank
Literature survey	50	170	0.294	1
Expert survey	20	170	0.118	4
Stakeholders Survey	40	170	0.235	3
Sponsors Preference	10	170	0.059	5
Data availability	50	170	0.294	1

Table 6.2 Table showing the final weights of importance of the eight factors considered in the present study as determined by AHP and FDM method

		Weights	0.294	0.118	0.235	0.059	0.294	Weights	Ranks
			Expert survey	Stakeholders survey	Literature review	Sponsors preference	Data availability	Final weight	
Rank of importance	Frequency of Troughs in Annual Hyetograph (P)	P	1	1	2	5	1	0.256	
	Frequency of Peak in Annual Hydrograph (Q)	Q	1	1	1	5	2	0.248	
	Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	Dd	4	4	5	2	7	0.097	
	Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	Da	4	4	6	2	6	0.098	
	Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	Di	4	4	3	2	3	0.132	
	Percentage Impervious Area (last 10 years) (A)	A	7	7	6	7	3	0.088	
	Annual Average Area of Canopy (Ac)	Ac	7	7	3	7	3	0.101	
	Frequency of Troughs in Annual Water Quality Index curve (WQI)	WQI	1	1	6	1	7	0.169	
AHP	Frequency of Troughs in Annual Hyetograph (P)	P	0.278	0.278	0.174	0.064	0.340	0.259	1
	Frequency of Peak in Annual Hydrograph (Q)	Q	0.278	0.278	0.349	0.064	0.170	0.250	2
	Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	Dd	0.069	0.069	0.070	0.160	0.049	0.069	6
	Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	Da	0.069	0.069	0.058	0.160	0.057	0.068	7
	Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	Di	0.069	0.069	0.116	0.160	0.113	0.099	4
	Percentage Impervious Area (last 10 years) (A)	A	0.040	0.040	0.058	0.046	0.113	0.066	8
	Annual Average Area of Canopy (Ac)	Ac	0.040	0.040	0.116	0.046	0.113	0.080	5
	Frequency of Troughs in Annual Water Quality Index curve (WQI)	WQI	0.278	0.278	0.058	0.320	0.049	0.161	3

(continued)

Table 6.2 (continued)

		Weights	0.294	0.118	0.235	0.059	0.294	Weights	Ranks
			Expert survey	Stakeholders survey	Literature review	Sponsors preference	Data availability	Final weight	
FLDM	Frequency of Troughs in Annual Hyetograph (P)	P	0.288	0.288	0.176	0.131	0.288	0.252	1
	Frequency of Peak in Annual Hydrograph (Q)	Q	0.288	0.288	0.216	0.131	0.235	0.246	2
	Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	Dd	0.157	0.157	0.098	0.235	0.078	0.125	6
	Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	Da	0.157	0.157	0.078	0.235	0.105	0.128	5
	Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	Di	0.157	0.157	0.137	0.235	0.183	0.165	4
	Percentage Impervious Area (last 10 years) (A)	A	0.078	0.078	0.078	0.078	0.183	0.109	8
	Annual Average Area of Canopy (Ac)	Ac	0.078	0.078	0.137	0.078	0.183	0.123	7
	Frequency of Troughs in Annual Water Quality Index curve (WQI)	WQI	0.288	0.288	0.078	0.288	0.078	0.177	3

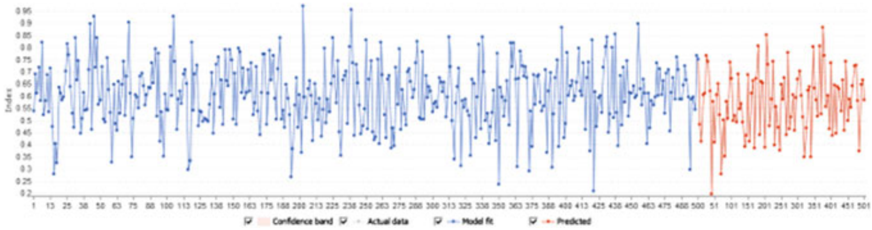

Fig. 6.1 Figure showing the comparison of actual data, model fit and predicted data of the model

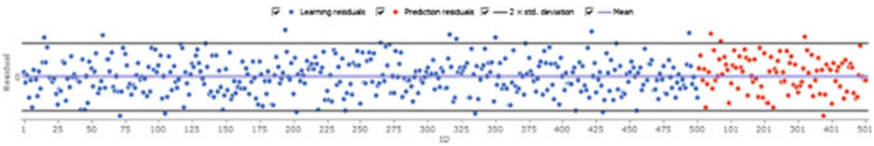

Fig. 6.2 Figure showing the residual errors of the model in the learning and prediction phase

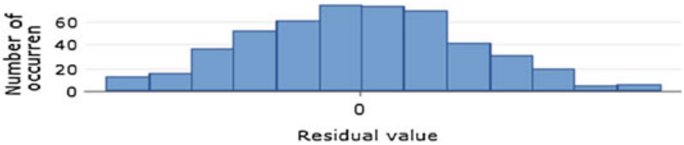

Fig. 6.3 Figure showing the frequency distribution of residual error

most of the deviations between the modelled and actual data are near to zero (Fig. 6.3).

The model equation for the developed neural network framework is given in Eq. 6.1.

$$V = 2.04026e{-}14 + P \times 0.2557 + Q \times 0.248136 + Dd \times 0.0966396 + Da \times 0.0980004 + Di \times 0.131631 + A \times 0.0876199 + Ac \times 0.10138 + WQI \times 0.169 \quad (6.1)$$

The performance metrics of the model is shown in Table 6.3. The Model Fit column of the table shows the performance of the model during the training process.

The Predictions column depicts the performance of the framework in the prediction stage, i.e., the input data for which model has predicted the output was not included in the data with which the model was trained.

From the table it can be clearly observed that mean absolute error was about 0.52 % more in Prediction stage with respect to the Training phase which is natural because at the time of prediction the model has to predict the output for unknown

Table 6.3 Table showing the performance metrics of the model

Performance metrics	Model fit	Predictions
Maximum negative error	-1.22×10^{-14}	-1.21×10^{-14}
Max positive error	1.44×10^{-14}	1.32×10^{-14}
Mean absolute error	4.19×10^{-15}	4.41×10^{-15}
Root mean square error	5.21×10^{-15}	5.33×10^{-15}
Standard deviation of residuals	5.21×10^{-15}	5.29×10^{-15}
Correlation coefficients	1	1

situations of the inputs. The Root Mean Square Error is also higher by 2.3 % in Prediction stage compared to training phase. But the correlation coefficient was found to be same for both the phases.

According to the performance metrics shown in Table 6.3 the model can be concluded as satisfactorily trained and ready for predictions of the unknown scenarios.

6.3 Results from the Sensitivity Analysis

A sensitivity analysis was also performed to test the sensitivity of the model to test whether the influence of parameters depicted by weights of importance was successfully corroborated into the model predictions. According to Fig. 6.4 the

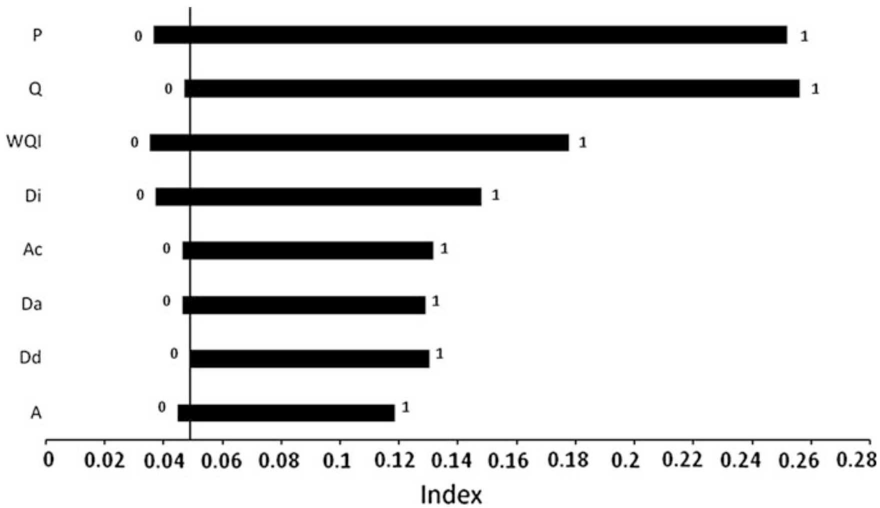

Fig. 6.4 Figure showing the sensitivity of each of the parameters towards the index

Table 6.4 Table showing the swing of the factors in the model

Input variable	Percent swing (%)
P	31.2
Q	29.4
WQI	13.6
Di	8.3
Ac	4.9
Da	4.6
Dd	4.5
A	3.7

tornado diagram of sensitivity analysis depicts that the sensitivity of the most and least important parameter of the model is same as the highest and lowest important parameter as found by the MCDM technique and represented by the weights of importance.

The Swing Percentage also seconded this conclusion. The results from the sensitivity analysis confirmed that the model was successful in mapping the importance of the parameters in the output (Table 6.4).

6.4 Scenario Analysis

The model was applied for the situation in Farakka Barrage in the Ganga River, Mahi on River Mahi and Peranai in River Vaigai. Table 6.5 shows the model output. From the results it can be clearly concluded that Peranai and Farakka are most and least vulnerable regions to the problems of water shortage. The severity of water scarcity is most in Peranai followed by Mahi and Farakka. The real situation of these places seems to match with the manner in which the index has represented the water shortage situation.

The climatic impact was also analyzed with the help of the index for these same three locations (Table 6.6).

In the normal scenario that is the present situation Vaigai has the highest level of water scarcity followed by Mahi and Farakka. The shortage of water availability is highest in Vaigai. More than the other two locations considered in the study. Mahi has the highest availability of water followed by Farakka.

In case of A2 scenario Mahi has the higher level of water scarcity than the other two locations for all the three time slabs although the intensity reduces in the 2071–2100 time slab. For B2 scenario Mahi has the highest level of water shortage in the last time slab but Farakka and Vaigai has the higher level of scarcity in the middle and first time slab respectively.

Table 6.5 Table showing the situation of the parameters in the three selected locations under normal and changed climate scenario (ranked in descending manner i.e. higher value receives higher rank)

Parameters	Value of the parameters			Normalized value			Scenario
	Farakka	Mahi	Vaigai	Farakka	Mahi	Vaigai	
Frequency of Troughs in Annual Hyetograph (P)	4	3	3	0.400	0.300	0.300	Normal scenario
Frequency of Peak in Annual Hydrograph (Q)	1	1	3	0.200	0.200	0.600	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	2	3	2	0.286	0.429	0.286	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	3	3	3	0.333	0.333	0.333	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	2	6	2	0.200	0.600	0.200	
Percentage Impervious Area (last 10 years) (A)	35	55	25	0.304	0.478	0.217	
Annual Average Area of Canopy (Ac)	65	45	75	0.351	0.243	0.405	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	4	8	6	0.222	0.444	0.333	
Frequency of Troughs in Annual Hyetograph (P)	6	4	4	0.429	0.286	0.286	A2: 2010–2030
Frequency of Peak in Annual Hydrograph (Q)	3	4	4	0.273	0.364	0.364	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	4	6	3	0.308	0.462	0.231	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	4	5	5	0.286	0.357	0.357	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	6	9	4	0.316	0.474	0.211	
Percentage Impervious Area (last 10 years) (A)	55	75	35	0.333	0.455	0.212	
Annual Average Area of Canopy (Ac)	45	25	65	0.333	0.185	0.481	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	2	7	5	0.143	0.500	0.357	
Frequency of Troughs in Annual Hyetograph (P)	7	5	5	0.412	0.294	0.294	A2: 2031–2070
Frequency of Peak in Annual Hydrograph (Q)	4	5	5	0.286	0.357	0.357	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	5	7	4	0.313	0.438	0.250	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	5	7	6	0.278	0.389	0.333	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	7	11	5	0.304	0.478	0.217	
Percentage Impervious Area (last 10 years) (A)	65	85	45	0.333	0.436	0.231	
Annual Average Area of Canopy (Ac)	35	15	55	0.333	0.143	0.524	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	4	8	6	0.222	0.444	0.333	

(continued)

Table 6.5 (continued)

Parameters	Value of the parameters			Normalized value			Scenario
	Farakka	Mahi	Vaigai	Farakka	Mahi	Vaigai	
Frequency of Troughs in Annual Hyetograph (P)	8	6	6	0.400	0.300	0.300	A2: 2071–2100
Frequency of Peak in Annual Hydrograph (Q)	5	6	6	0.294	0.353	0.353	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	6	7	5	0.333	0.389	0.278	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	6	7	7	0.300	0.350	0.350	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	9	11	7	0.333	0.407	0.259	
Percentage Impervious Area (last 10 years) (A)	75	84	55	0.350	0.393	0.257	
Annual Average Area of Canopy (Ac)	25	16	45	0.291	0.186	0.523	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	5	9	3	0.294	0.529	0.176	
Frequency of Troughs in Annual Hyetograph (P)	3	2	2	0.429	0.286	0.286	B2: 2010–2030
Frequency of Peak in Annual Hydrograph (Q)	2	2	3	0.286	0.286	0.429	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	4	6	5	0.267	0.400	0.333	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	3	6	6	0.200	0.400	0.400	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	2	2	2	0.333	0.333	0.333	
Percentage Impervious Area (last 10 years) (A)	35	55	25	0.304	0.478	0.217	
Annual Average Area of Canopy (Ac)	65	45	75	0.351	0.243	0.405	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	2	2	2	0.333	0.333	0.333	
Frequency of Troughs in Annual Hyetograph (P)	2	2	3	0.286	0.286	0.429	B2: 2030–2070
Frequency of Peak in Annual Hydrograph (Q)	3	2	2	0.429	0.286	0.286	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	5	5	4	0.357	0.357	0.286	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	5	3	4	0.417	0.250	0.333	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	3	2	1	0.500	0.333	0.167	
Percentage Impervious Area (last 10 years) (A)	30	50	40	0.250	0.417	0.333	
Annual Average Area of Canopy (Ac)	70	50	60	0.389	0.278	0.333	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	3	4	2	0.333	0.444	0.222	

(continued)

Table 6.5 (continued)

Parameters	Value of the parameters			Normalized value			Scenario
	Farakka	Mahi	Vaigai	Farakka	Mahi	Vaigai	
Frequency of Troughs in Annual Hyetograph (P)	2	2	2	0.333	0.333	0.333	B2: 2071–2100
Frequency of Peak in Annual Hydrograph (Q)	2	2	2	0.333	0.333	0.333	
Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd)	5	6	5	0.313	0.375	0.313	
Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da)	5	5	7	0.294	0.294	0.412	
Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di)	4	4	3	0.364	0.364	0.273	
Percentage Impervious Area (last 10 years) (A)	25	40	35	0.250	0.400	0.350	
Annual Average Area of Canopy (Ac)	75	60	65	0.375	0.300	0.325	
Frequency of Troughs in Annual Water Quality Index curve (WQI)	3	3	2	0.375	0.375	0.250	

Table 6.6 Table showing the predicted index value for the selected locations under normal and changed climate scenarios

Case study	P	Q	Dd	Da	Di	A	Ac	Model1.Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.4	0.2	0.286	0.333	0.2	0.304	0.351	0.343	3
Mahi (Mahi River)	0.3	0.2	0.428571	0.333333	0.6	0.478261	0.243243	0.409	2
Peranai (Vaigai River)	0.3	0.6	0.285714	0.333333	0.2	0.217391	0.405405	0.435	1

Scenario: A2; Time slab 2010–2030

Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1. Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.428571	0.272727	0.307692	0.285714	0.315789	0.333333	0.333333	0.142857	0.363705	3
Mahi (Mahi River)	0.285714	0.363636	0.461538	0.357143	0.473684	0.454545	0.185185	0.5	0.448344	1
Peranai (Vaigai River)	0.285714	0.363636	0.230769	0.357143	0.210526	0.212121	0.481481	0.357143	0.376058	2

Scenario: A2; Time slab: 2031–2070

Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1. Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.411765	0.285714	0.3125	0.277778	0.304348	0.333333	0.333333	0.222222	0.374224	3
Mahi (Mahi River)	0.294118	0.357143	0.4375	0.388889	0.478261	0.435897	0.142857	0.444444	0.434958	1
Peranai (Vaigai River)	0.294118	0.357143	0.25	0.333333	0.217391	0.230769	0.52381	0.333333	0.378925	2

Scenario: A2; Time slab: 2071–2100

Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1.Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.4	0.294118	0.333333	0.3	0.333333	0.350467	0.290698	0.294118	0.390636	2
Mahi (Mahi River)	0.3	0.352941	0.388889	0.35	0.407407	0.392523	0.186047	0.529412	0.432522	1
Peranai (Vaigai River)	0.3	0.352941	0.277778	0.35	0.259259	0.257009	0.523256	0.176471	0.364949	3

Scenario: B2; Time slab: 2010–2030

Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1. Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.428571	0.285714	0.266667	0.2	0.333333	0.304348	0.351351	0.333333	0.38835	3
Mahi (Mahi River)	0.285714	0.285714	0.4	0.4	0.333333	0.478261	0.243243	0.333333	0.388585	2
Peranai (Vaigai River)	0.285714	0.428571	0.333333	0.4	0.333333	0.217391	0.405405	0.333333	0.411173	1

(continued)

Table 6.6 (continued)

Scenario: B2; Time slab: 2030–2070										
Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1. Index	Rank w.r.t water shortage
Scenario: B2; Time slab: 2030–2070										
Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1. Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.285714	0.428571	0.357143	0.416667	0.5	0.25	0.388889	0.333333	0.438228	1
Mahi (Mahi River)	0.285714	0.285714	0.357143	0.25	0.333333	0.416667	0.277778	0.444444	0.386625	2
Peranai (Vaigai River)	0.428571	0.285714	0.285714	0.333333	0.166667	0.333333	0.333333	0.222222	0.363254	3
Scenario: B2; Time slab: 2071–2100										
Case study	P	Q	Dd	Da	Di	A	Ac	WQI	Model1. Index	Rank w.r.t water shortage
Farakka (Ganga River)	0.333333	0.333333	0.3125	0.294118	0.363636	0.25	0.375	0.375	0.398132	2
Mahi (Mahi River)	0.333333	0.333333	0.375	0.294118	0.363636	0.4	0.3	0.375	0.409712	1
Peranai (Vaigai River)	0.333333	0.333333	0.3125	0.411765	0.272727	0.35	0.325	0.25	0.380263	3

In case of A2 the last time slab was found to be worse for all the three locations whereas in case of B2 the middle time slab shows the higher level of scarcity than the other two time slabs.

Mahi has the higher level of urbanization followed by Vaigai and Farakka. Vaigai is also geo-physically prone to water scarcity. Its catchment has low water retention capacity. That is why in the normal situation also, Vaigai has the highest level of scarcity compared to other two locations. As an impact of Climate change situation of Mahi worsens in A2 but change in scarcity level is highest for Farakka from first to middle time slab in B2 scenario of climate change. Again in A2 scenario Mahi was clearly found to be most vulnerable but in case of B2 all three locations become most vulnerable in the three different time slabs.

The reason can be attributed to the strict environmental regulations that will be imposed on the locations and also to detrimental increase of population which becomes highest in the middle time slab but in the last slab change in density reduces compared to other two time slabs. Whereas in A2 scenario a steady increase in population density was predicted.

The Figs. 6.5 and 6.6 shows the comparison of the value of index in the selected region under three time slabs of A2 and B2 scenario.

The index developed with the help of MCDM techniques and ANN model seems to be performing satisfactorily. The introduction of this index will help the engineers and city planners to identify vulnerable regions with respect to water availability. Thus allocation of funds for mitigation will also become easier and logical.

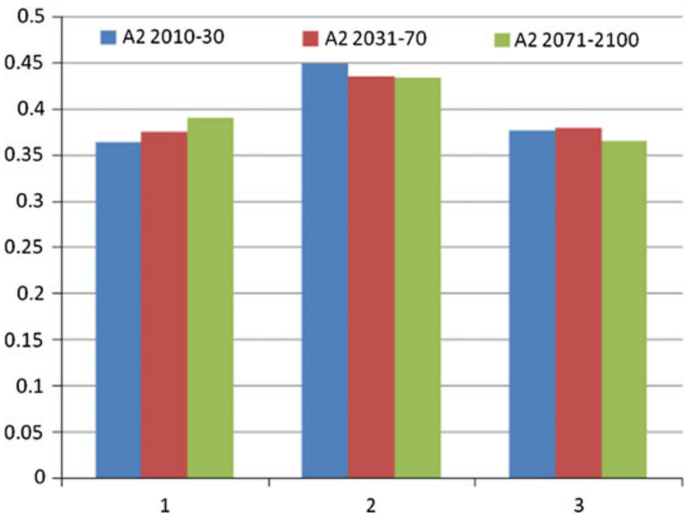

Fig. 6.5 Figure showing the index value for the three time slabs of A2 Scenario (*1* Farakka, *2* Mahi, *3* Peranai)

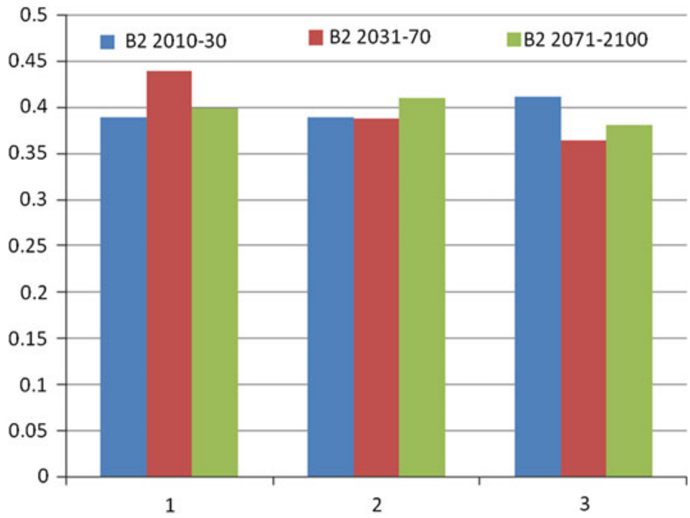

Fig. 6.6 Figure showing the index value for the three time slabs of B2 scenario (*1* Farakka, *2* Mahi, *3* Peranai)

6.5 Discussions

The index developed with the help of MCDM techniques and ANN model seems to be performing satisfactorily. The introduction of this index will help the engineers and city planners to identify vulnerable regions with respect to water availability. Thus allocation of funds for mitigation will also become easier and logical.

The proposed index takes the output from both human and documentary sources. That is why, both subjective and objective decision making can be incorporated in the index. As the index is cascaded with the ANN model, the necessity for repeat application of the MCDMs whenever a new location is included in the decision making becomes void. Thus it saves time as well as maintains uniformity in the decision making. The inclusion of normalized value of the input ensures that no error due to scale difference of the factors can be included. The factors were collected after a thorough search within the available and related literatures. This withholds the objectivity of the selection of factors without any human interference. But as the anthropogenic holisticity can not be denied, the feedback about the factors from the experts and stakeholders are also included.

The major disadvantage of the index is it requires the data for eight parameters which is often a tedious and difficult work to accomplish. But as the index accepts normalized value only the ranked values of the factors can be used. Another issue of concern is the value for the two similar locations becomes nearly equal having differences like 0.001–0.002. In this regard the hairline difference between the two index value will makes it difficult for the decision maker to interpret. But if the percentage of the index value is incorporated the difference is somehow becoming prominent.

The index provided the opportunity to identify the vulnerable regions logically and in an objective manner. With the help of the index, fund allocation for taking mitigative actions so that the deterioration of the situation can be prevented.

The fund allocation will be realistic and less controversial due to its need based nature. The hostility which are commonly observed in case allocation of development funds can also be nullified. The index can also be used to develop a country wise or watershed wise maps depicting the variation of water shortage within the selected range. The map can be prepared for present or normal as well as uncertain scenarios due to climatic and urbanization changes.

Chapter 7
Conclusion

Abstract The present investigation tried to establish a new methodology for estimation of water shortage as a function of urbanization, climatic parameters and water quality. The new index for estimation of the intensity of water scarcity also assigned weights of importance to the selected parameters so that the sensitivity of the parameters towards representation of the intensity of water shortage can be reflected by the indicator. The indicator also includes the impact of temporal variability of the parameters by considering the amplitudes rather than discrete magnitudes like mean values. The indicator was validated by the estimation of water shortage in three locations having different levels of urbanization. The indicator was applied to find the severity of water scarcity in this three locations under six different climate change scenarios. The highest and lowest important parameter among the eight input parameters considered in the study was found to be Frequency of Troughs in Annual Hyetograph (P) and Percentage Impervious Area (A) respectively. If criteria by which the importance of the alternatives are compared it can be said that five criteria were considered. Among which Literature Survey and Data Availability and Sponsor's Preference was found to be the most and least important criteria respectively. A limitation of the index is it does not explicitly differentiate between the sources of abstractions. But represent it by the demand from the consumers. The water availability is depicted by the rainfall and runoff parameters along with the WQI for consideration of quality of the water. Another limitation of the new indicator is it is location specific. But as the selected parameters can depict the impact of the adjacent locations the parameters of the nearest regions are not included. Again the indicator represent the water shortage based on the extreme values of the parameters. Thus if the indicator shows a severe shortage of water it means the situation is more vulnerable than represented by the indicator. But considering a situation based on extreme values may be beneficial for the related professional. The system will only alert them if and only if the situation requires attention. In this way both man hour and money can be saved. The indicator utilized eight parameters. Among which some are directly proportional to shortage of water and some are inversely proportional. The same is represented by taking the peak and trough values of the parameters which are respectively directly and inversely proportional to the severity of water scarcity.

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Keywords Index · Water scarcity · Climate change · MCDM · ANN

7.1 Summary

In the present investigation an attempt was made to identify the regions which are vulnerable to climate change in terms of water availability. In this regard a new index was proposed. The input parameters of the index is selected based on survey of literatures, discussion with the experts, sponsors and stakeholders along with availability of data of the selected input variable. According to the results of survey and discussions, Frequency of Troughs in Annual Hyetograph (P), Frequency of Peak in Annual Hydrograph (Q), Frequency of Peaks in Annual Water Demand curve for Domestic Consumers (Dd), Frequency of Peaks in Annual Water Demand curve for Agriculture Consumers (Da), Frequency of Peaks in Annual Water Demand curve for Industrial Consumers (Di), Percentage Impervious Area (last 10 years) (A), Annual Average Area of Canopy (Ac) and Frequency of Troughs in Annual Water Quality Index curve (WQI) parameters are found to be preferred. That is why this eight parameter was taken as input variable. The output will be the index which is actually the weight function of all the eight parameters.

Once the input variables are selected in the weight of importance of the parameters were calculated with the help of MCDM methods like Fuzzy-AHP and FLDM method. The weights of the input parameters as derived from the two methods were averaged and utilized as the weights of the weight function.

The index is then cascaded into ANN model for ready prediction of the indicator. In case of ANN model feed-forward neural architecture was used with optimal topology decided by the Genetic Algorithm. The model was trained with two training algorithms and Combinatorial Polynomial Neural Network was found to yield more satisfactorily results than the other method.

The index was applied in three cases having different levels of urbanization. The impact of climate change was also predicted for the same regions. The climatic impact on the availability of water for the two scenarios A2 and B2 was predicted for three time slabs: 2010–30, 2031–70 and 2071–2100.

According to the predicted index values for the climate change scenarios the worst situation was observed in the 2071–2100 time slabs for A2 and 2031–2070 time slab for B2 scenario. The strict regulation on industries in the B2 Scenario may be attributed for the improvement of the water scarcity in the last time slab.

The change in population as predicted by World Bank can also be a reason for this type of observations. As in A2 a steady increase is predicted the situation get worsened in the last time slab only. But in case of B2 change in population receded in the last time slab. So the situation improved in the 2071–2100 time slab.

7.2 Drawbacks

The index has the following drawbacks:

1. The indicator does not separately represents the source of abstraction.
2. The index is location specific.
3. The indicator represents the status of water shortage with the help of extreme values of the input parameters.

7.2.1 Source of Abstraction

Many other related indicator has in fact included the source of abstraction as a parameter. But as the demand from the consumers and availability of the resources is represented by the causal variables the need of explicit representation of the type of source is not required. Both rainfall and runoff controls the availability of water in a region. The amount of infiltration can be estimated by the area of canopy cover. Thus all the independent parameters of the water availability is explicitly considered so need of mentioning the type of source is not necessary as the objective was to depict water shortage not the impact of type of source on water shortage.

7.2.2 Location Specific

The index is location specific. That means it considers the amplitude of the location for which the indicator value is being calculated.

But as the considered parameters can represent the influence of the adjacent location the impact of the nearest locations are not explicitly considered.

The value of the parameters is actually a result of the influence of both the present and adjacent locations. So if we considered the values of the adjacent locations the indicator would have estimated the situation based on the overlapped values of the input parameters.

7.2.3 Estimation Based on Extreme Condition

The extreme values like peak or trough of the input parameters which are respectively directly and indirectly proportional to the severity of water shortage is considered while estimating the value of the index.

In this way the indicator may alert the user at the time of emergency only. But on the other hand by taking measures only when required enables saving of money and manhour. That is why instead of over reacting to a situation the indicator makes it possible to optimally react to a really grave situation.

7.3 Future Scope

A country wide watershed map can be generated to enable planners identify vulnerable regions.

Some factors of the index may be removed if become extremely tedious to collect data for six parameters or a parameter may become unimportant due to the change in the situation.

The present version may be utilized first and according to the feedback received from the user, the least or unwanted factors can be withdrawn from the index to make the index less time consuming and more specific to the problem.