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Environmental Problems of Central Asia and their Economic, Social and Security Impacts

Edited by
Jiaguo Qi
Kyle T. Evered

Springer

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Environmental Problems of Central Asia and their Economic, Social and Security Impacts

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Series C: Environmental Security

Environmental Problems of Central Asia and their Economic, Social and Security Impacts

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FOREWORD

The Aral Sea that was once a thriving body of water is no more. That sea is dead. "Long Live the Aral Sea". What does exist in its place are the Aral Seas, that is, there are in essence three bodies of water, one of which is rising (the Little Aral), while the other two, though marginally still connected, continue to decline in level. In 1960 the level of the sea was about 53 m above sea level. By 2006 the level had dropped by 23 to 30 m above sea level. This was not a scenario generated by a computer model. It was a process of environmental degradation played out in real life primarily as a result of human activities. Despite wishes and words to the contrary, it will take a heroic global effort to save what remains of the Big Aral. It would even take a degree of sacrifice to restore it to a previous acceptable level.

The setting

There are several countries in the Aral Sea Basin. Most people refer to the five former Central Asian Republics of the Soviet Union as ***THE*** basin states: Turkmenistan, Kazakhstan, Uzbekistan, Kyrgyzstan and Tajikistan. However, Afghanistan and Iran are also in the basin, with only 1% on Iranian soil and an estimated 17% on Afghanistan's soil. The two major regional rivers are the Amu Darya (darya is river in the Turkic language) and the Syr Darya. The former is about twice the size of the latter with the Amu Darya carrying about 70 km^3 per year on average. The Amu Darya begins in the Pamirs and flows through Tajikistan and Afghanistan before it starts its decent toward the sea, passing through Turkmenistan and Uzbekistan. The Syr Darya also starts in Tajikistan and Kyrgyzstan and passes to the sea through a long stretch of Kazakhstan territory. Aralsk in Kazakhstan and Myunak in Uzbekistan were major fishing ports in the Aral Sea supporting into the 1960s a fishing sector of about 60,000 workers.

In fact, there is a third major river in Central Asia, the Karakum Canal. This is in essence a manmade river, much of which is an unlined canal dug out of the desert sands, the construction of which began in the mid-1950s. It was designed to bring water to the least populated, most desertified country of the five Soviet Republics, Turkmenistan. It was over 1,000 km long and in recent years was extended about 300 additional km by the late president Niyazov.

The demise of the Aral Sea did not occur overnight, but it did not take centuries either. It happened in a period of four to five decades. The discussions about whether to exploit the sea's waters took a bit longer than did the sea's recent decline. In 1908 Russian scientists first spoke of tapping the sea's waters for "useful" purposes (read that as using the water for purposes suited to the needs of the Russian Empire). It was in the 1950s that Soviet leaders decided to sharply expand cotton production in the basin which required a major increase in diversions from the regions two major rivers. In that decade plans were developed that, around 1960, put into practice by the Soviet Politburo in the Kremlin sought to double the amount of hectares planted for cotton production. It was at about 4 million hectares then and was planned to go to about 8 million hectares devoted to cotton production. Hence, the necessity of increasing diversions from the rivers that fed the sea.

After 1960, increasing amounts of water were diverted from the Amu Darya and the Syr Darya primarily in order to increase cotton production. Cotton has been the major crop in Central Asia, as the climate and soils were perfect for it. The missing ingredient in this equation was water. The rate at which diversions were made up to the 1950s was apparently below a threshold of adverse impacts on streamflow into the sea. Aside from its normal annual, decadal and other time scale fluctuations, human activities began to impinge on the quantity reaching the sea in the 1950s.

The drying out of the Aral Sea turns out to be a perfect example of a "creeping" environmental change. These are environmental changes that are low grade, incremental but cumulative over time for which no obvious thresholds (step-like or irreversible change) can be identified in advance of crossing that threshold. Such changes almost always become creeping environmental problems (or CEPs), if not crises, which then demand the full attention of policy makers from the local to the national level.

The Aral Sea was once the world's fourth-largest inland sea. Its surface area once measured 66,100 km^2 (25,521 square miles). Its problems began in the 1960s and 1970s with the diversion of the main rivers that feed it. By 1987, the Aral Sea had lost about 60% of its volume, its depth had dropped by 14 m (45 ft), and its salt concentration had doubled, killing the commercial fishing industry. Wind storms carried toxic dust onto farms a few hundred kilometers downwind, transporting fine grains of pesticide- and herbicide-laden dust that had been deposited for decades on the exposed sea floor. Life expectancies in the districts near the sea are significantly lower than in surrounding areas. The sea is now a quarter of the size it was 50 years ago and has broken into several parts, the North Aral Sea and the South Aral Sea (which is nearly separated in to two parts). Re-engineering a barrier to separate the Little (North) Aral from the Big Aral has served to retain water in the North Aral Sea.

The science related to the Aral Sea is actually quite easy to understand, as complex as its components and their interactions might be. Many studies over at least half a century have provided researchers with considerable amounts of data relating to the climate, water and soils. The hydrological balance is known as are the many ways that settlements have interfered with or disrupted it. Clearly there is more water leaving the Aral Sea than is entering it (through land surface and sea water evaporative processes and water diversion to an adjacent basin).

Cotton has been blamed for the demise of the sea and the poisoning of the water and agricultural lands. Fertilizers, herbicides and pesticides were applied to the cotton fields in great amounts, based on the assumption that if a small amount did some good than a lot would do even greater good for cotton production. It was revered as a crop and for the high level of production in the region. Little political attention was paid, however, to the environmental costs associated with cotton production. Quotas set in Moscow drove regional political leaders and collective farm managers to push hard on the workers to meet the unrealistic quotas, quotas that were often met only on papers sent back to Moscow. There are now many documented accounts about how the cotton production statistics were manipulated to please the Politburo thousands of kilometers away from Central Asia.

To be fair to policy makers, the problems related to the Aral Sea were not the only ones these leaders had to face. Recall that the sea had been dropping slowly over time and not changing in notably sharp, step-like increments. These leaders have had to juggle many issues at the same time. The issues noted in the following list are meant to be illustrative and are not presented in order of priority. Under "normal" conditions, the five Central Asian Basin states (and Afghanistan) operate in a multi-stressed environment.

Diverted streamflow	Pesticide & fertilizer use
Declining water quantity	Declining water quality
Shortened life expectancy	Ethnic conflicts
Rapid sea level drop	Contaminated aerosols
Loss of biological productivity	Dust storms
Loss of biological diversity	Karakum Canal
Loss of wildlife and forests	Five competing nations
Islamic fundamentalist threat	Terrorist groups
Upstream-downstream issues	Authoritarian regimes
Oil & gas haves vs. have-nots	Global warming
Hotter summers, colder winters	Loss of cultural heritage

Admittedly, it is easy to sit in an armchair far away from Central Asia and advise the leaders of the Central Asian republics about the need to break their dependence on cotton or to use water more efficiently. It is also easy to tell them that they must cooperate on issues related to the efficient management and use of water resources and related water supply issues. But to make the needed drastic changes is much easier said than done.

The contributions to this volume represent sincere research efforts to improve the understanding of how the sustainability of Aral Basin ecosystems, water resources, soils, and human activities has each been undermined not precipitously but slowly over time. And, as creeping (slow onset, incremental but cumulative over time) as has been the widespread degradation throughout the basin, likely as creeping will be its rehabilitation. Sustained monitoring of environmental and social change and continued research to identify potential pathways to rehabilitate local and regional ecosystems and societies are a necessity if leaders in the region have any hope for long term economic progress.

Michael Glantz
Boulder, Colorado, June 2008

PREFACE

Central Asia is largely arid and semi-arid and therefore very sensitive to environmental perturbations. Recent changes in social structures, accompanied by regional climate change, have caused substantial environmental changes leading to security concerns in the region. Water levels in the major rivers of the region, the Amu Darya and Syr Darya have been reduced significantly due to overdraws along their courses from intensified irrigation and industrial use. Soil salinization problems have worsened due to increased surface evaporation. Snow covers and glaciers have receded due to regional climate change and thus reduced freshwater supplies to the region. As a result, the local economy has been significantly impacted to the extent that the potential for social unrest is a big concern. There is a need to develop new technologies and adaptation strategies to mitigate these environmental problems and cope with continued environmental change.

In order to address these issues, regional experts from 13 countries gathered together for an international workshop sponsored by the NATO Science for Peace and Security Program in Tashkent, October 1–5, 2007, to share information about ongoing efforts in the region. Their areas of expertise included climate science and modeling, land use/cover change, biogeochemical processes, socioeconomics, resource management, and geospatial technologies. Specific science questions the experts addressed were:

1. What are the emerging environmental and societal issues of the region?
2. What are the state-of-the-art research methodologies used in addressing these issues?
3. What technologies are available to help mitigate the environmental and societal issues of the region?
4. Finally, what institutional policies should be implemented to mitigate the emerging environmental issues?

This book highlights research efforts that address one or more of these questions using case studies as a demonstration of mitigation and adaptation strategies for environmental problems in Central Asia. It is hoped that these studies will serve as examples that can be scaled up and transferred to decision makers in an effort to implement effective policies and management practices.

The editors are grateful for the contributions of the authors, both to the workshop and to this book. We would like to give our sincerest thanks as well to the dedicated staff members in Uzbekistan who overcame numerous

logistic challenges to make this workshop possible. Organizational support for this workshop was provided by the Scientific-Research Department of Ecology at the National University of Uzbekistan, the Heat Physics Department of the Uzbek Academy of Sciences, and the Center for Global Change and Earth Observations at Michigan State University.

Jiaguo Qi
East Lansing, Michigan, June 2008

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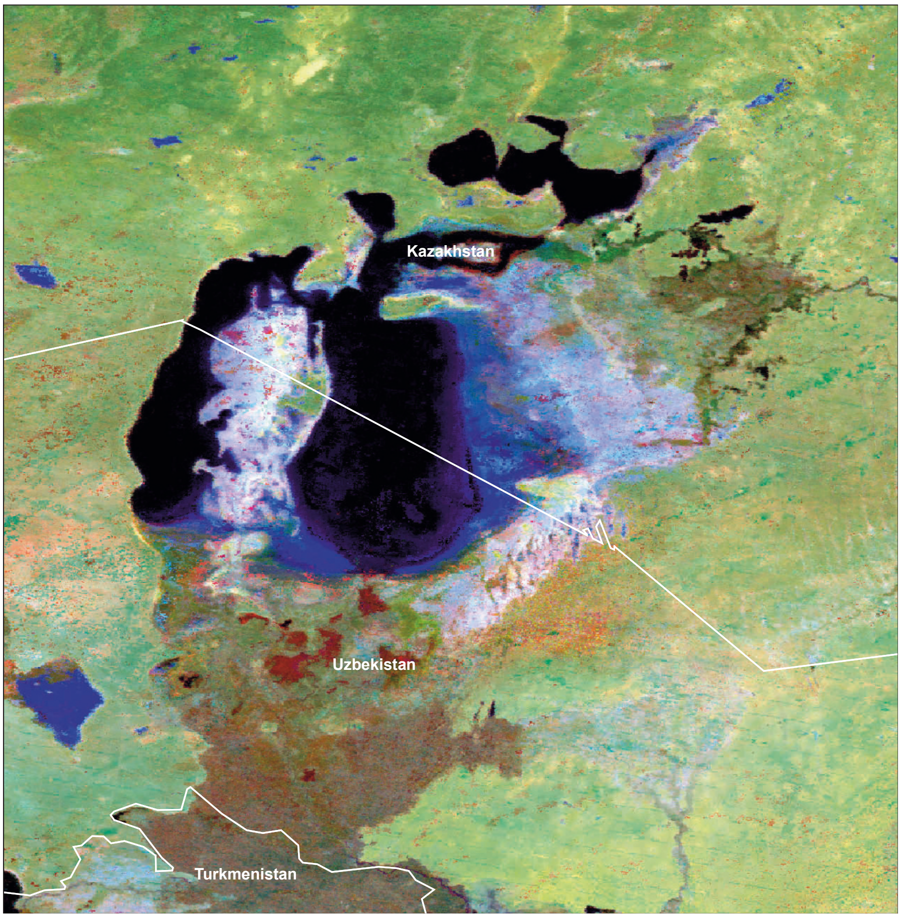

Aral Sea seen from Terra Satellite (MODIS Sensor).

AN OVERVIEW OF ENVIRONMENTAL ISSUES IN CENTRAL ASIA

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Abstract. The geographic area of Central Asia is largely arid and semi-arid and very sensitive to environmental perturbations. Recent changes in social structures and resource management practices, accompanied by regional climate change, have caused substantial environmental concerns. The Aral Sea has shrunk by almost 30% over the past two decades, the flow rate of the two major rivers in the region, the Amu Darya and Syr Darya, has been reduced significantly due to overdraws along their courses from intensified irrigation and industrial use, soil salinization problems have worsened due to increased surface evaporation, snow covers and glaciers have receded due to regional climate change and thus reduced freshwater supplies to the region, and, as a result, the local economy has been significantly impacted to the extent that the potential for social unrest is a big concern. There is a need to develop new technologies to mitigate these environmental problems and at the same time there is a critical need to develop adaptation strategies to cope with continued environmental change. This chapter outlines at a broad scale the environmental issues of the region and potential socioeconomic consequences.

Keywords: Central Asia, environment, water, degradation, land use

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1. Introduction

Central Asia is a region of Asia from the Caspian Sea in the west to Central China in the east, and from Southern Russia in the north to Northern India in the south (Figure 1). Though various definitions of its exact composition exist, no one definition is universally accepted. Despite this uncertainty in defining borders, it does have some important overall characteristics. For one, Central Asia historically has been closely tied to its nomadic peoples and the Silk Road. As a result, it has functioned as a crossroads for the movement of people, goods, and ideas between Europe, West Asia, South Asia, and East Asia. It is also sometimes known as Middle Asia or Inner Asia, and falls within the scope of the wider Eurasian continent.

Central Asia is largely coextensive with Turkistan. In modern context, Central Asia consists of the five former Soviet republics of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The nations of Afghanistan and Mongolia may also be included in Central Asia, in addition to the western Chinese provinces of Inner Mongolia, Xinjiang, Qinghai and Tibet. A small portion of Kazakhstan is also located west of the Urals in Eastern Europe (Figure 1).

The geography of Central Asia highly variable, as it is an extremely large region and includes high passes and mountains (Tian Shan), vast deserts (Kara Kum, Kyzyl Kum, Taklamakan), and especially treeless, grassy steppes. The vast steppe areas of Central Asia are considered together with the steppes of Eastern Europe as a homogenous geographical zone known as the Euro-Asian Steppe. The Gobi desert extends from the foot of the Pamirs, 77° east, to the Great Khingan (Da Hinggan) Mountains, 116°–118° east.

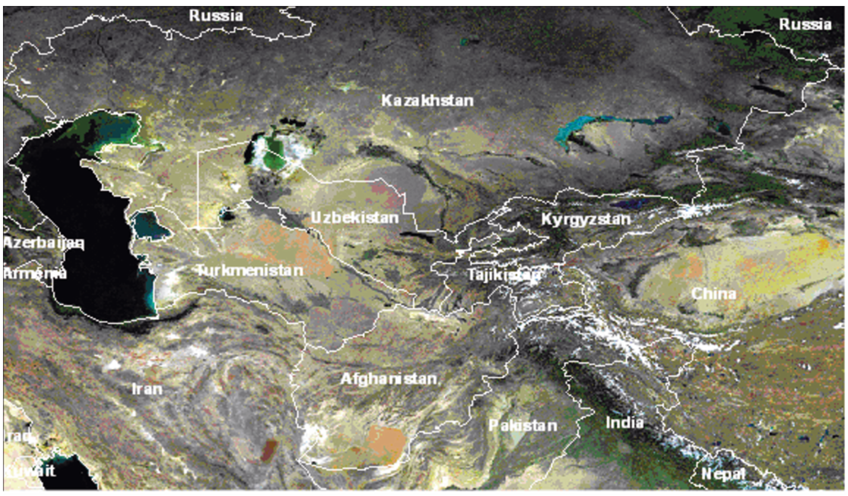

Figure 1. A composited MODIS image of Central Asia for the first week of August 2007.

A majority of the people of the region earn a living by herding livestock. Industrial activity centers in the region's cities. Much of Central Asia is dry land. Like other regions of the global drylands, Central Asia faces a myriad of problems that present tough research, management, and policy challenges. Although some restoration programs, such as the DDP in the AridNet (Reynolds et al., 2007), exist progress made so far is still limited.

Major rivers of the region include the Amu Darya, the Syr Darya and the Hari River. Major bodies of water include the Aral Sea and Lake Balkhash, both of which are part of the huge West/Central Asian endorheic basin that also includes the Caspian Sea. Both of these bodies of water have shrunk significantly in recent decades due to diversion of water from rivers that feed them for irrigation and industrial purposes. Water is an extremely valuable resource in arid Central Asia, as it is the major natural resource that sustains the region's agricultural food security (e.g., Glazovsky, 1995).

The climate of Central Asia is extremely variable as well, because of its wide range of topography. The mountains receive significant snows annually while the deserts have little to no rainfall at all, making the region extremely variable in precipitation and temperature (Lioubimtseva et al., 2005). However, changes in regional climate and anthropogenic activities have altered the regional temperature by about 5°C in the spring and summer and 4°C in the fall and winter while precipitation changes have shown a strong heterogeneous pattern (e.g., Small et al., 2001). With predicted future climate change the temperature is expected to further increase by 1–2°C by 2030–2050 while the precipitation changes differ spatially (Lioubimtseva et al., 2005).

2. Environmental issues of Central Asia

The region has experienced a variety of environmental problems, which seriously hinder the region's economy, food security and human health. One of the most serious environmental problems affecting the development of all Central Asian countries is the scarcity of water resources. The well known Aral Sea, due to reduced recharges from the two major rivers, the Amu Darya and the Syr Darya, has been split into three small bodies of water, one of which is being purposefully restored with some success (the Small Aral), and two others which are still marginally connected, although their water levels continue to decline (Glantz, 2007 and Figure 1). In 1960 the sea level was about 53 m with a total area of approximately 69,384 km^2 (Micklin, 1988; Peneva et al., 2004). By 2008 the Aral Sea level had dropped by 23–30 m (Micklin, 1988; Micklin, this book). The total surface water area of the Aral Sea was reduced from 69,384 to 16,810 km^2 during the same time period.

Regional climate change driven by global climate variability has contributed to a significant reduction in available water resources in the area. In much of the Central Asia, glaciers and ice-rich permafrost provide a continuous supply of fresh water to the lowlands and therefore irrigated agriculture of the region. Their recession over the past few decades as a result of global climate change has been obvious. This is well seen in the mountains of the northern Tian Shan range in Kazakhstan and China (Bolch and Marchenko, 2006). In the mountains of the northern Tian Shan range, it is also clear that the glaciers are melting very rapidly, losing about 0.7% of their mass per year from 1955–2000 (Gorbunov et al., 1998). Over this time period the glaciers reduced their total surface area from 272 to 201 km^2. The glacier recession is certain to impact the long-term freshwater availability of the region for agricultural food production (Groisman et al., 1994; Lioubimtseva et al., 2005).

Soil erosion and salinization in Central Asia was reported to be the worst in comparison with other continents (Lal, 1995, 2000), primarily in the form of water erosion. Central Asia deserves very special attention (Lal, 2000) as the population growth rate is high and lands are very vulnerable to wind and water erosion (Smalley et al., 2005). Soil erosion in Central Asia has adversely affected the region's economy (e.g., Pimentel et al., 1995; Montgomery, 2007) and has global environmental consequences (e.g., Prospero et al., 2002).

With increasing irrigation, salinization is accelerating and further reducing the productive agricultural lands. In the early 1960s, a large-scale irrigation campaign aimed at achieving independence in cotton production was launched in the former Soviet Union. Since then, ever-increasing water withdrawal from the Amu Darya and Syr Darya has resulted in the dramatic decline of available water resources (Saiko and Zonn, 2000). The intensified irrigation, which results in significant water loss through surface evaporation, has led to severe soil salinization that is very difficult to reverse. Another impact of increased surface irrigation was soil desiccation that further threatens agricultural productivity.

These environmental problems, particularly the reduced water supplies and soil degradation, and their associated societal consequences are influencing policy discussions regarding sustainable development of the region. To achieve economic development without sacrificing the environment, a key integrative question is: What are the appropriate tools and management practices available to mitigate the environmental problems, given increasingly variable climate patterns? There is a need to holistically investigate the root causes of and practical solutions to the emerging environmental issues of the region.

3. Human activities are the major drivers of environmental change

Although climate change might have contributed to overall water scarcity in Central Asia, increased human activities in the region can be identified as one of the major drivers of environmental problems, especially the disappearing Aral Sea. Diminishing of water supplies are a result of environmental degradation played out in real life in a matter of a few decades, primarily as a result of intensified water use to sustain expanding agricultural, industrial and residential needs.

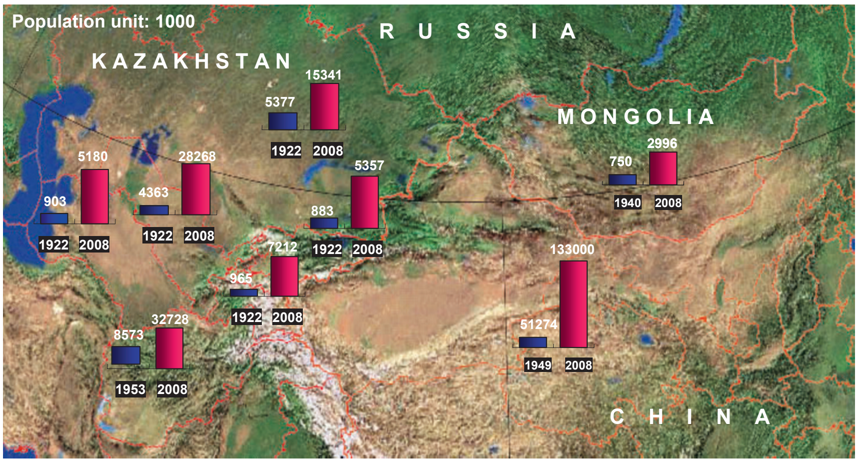

Figure 2. Population changes in Central Asia (unit: 1,000 people).

It is well known that, due to the agriculture-oriented economy in the Soviet period, Central Asian countries enlarged their irrigated lands during last twenty years. This led to a gradual increase in the amount of water used in agriculture and a corresponding decrease in the water feeding into the Aral Sea (actually a large saline lake), the area of which was comparable with the areas of some small seas before the mid of the last century. This irreversible process of the drying up of the Aral Sea led to considerable changes in the climate of the region causing additional catastrophic salinization of the soil in the Aral Sea basin and neighboring areas, a reduction in the air humidity, and other negative effects. In addition, rapid increases in population and extension of irrigated agricultural areas have caused water deficiency in the Aral Sea basin and Figure 2.

Shown in Table 1 (Glantz, 2005), the population of the five (5) nations of former Soviet Union (Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, and Tajikistan), Afghanistan, Mongolia, and China increased 3–5 times over the past 70 years. These increases in population came along with an increased demand for food and water. The intensified resource management practices in the region greatly stressed fragile ecosystems, especially aquatic ecosystems, and resulted in dramatic environmental degradation of the region (Zhang and Xu, 1999). The marginal lands of the regions are consequently overgrazed, and arable land uses for crop production have intensified, leading to significant land degradation, ground water table decrease, soil erosion and reduced surface water resources. According to the United Nations Convention to Combat Desertification, UNCCD (1994) for example, approximately 66% of Kazakhstan's lands experienced different levels of degradation and 15–20 of the arable lands have become deserts. Exponential increases in livestock in Mongolia greatly accelerated the desertification process of many of the country's grasslands. The population pressure induced grassland desertification is worse in China. In the western provinces of China (Xinjiang, Inner Mongolia, Gansu, Tibet, Qinghai, Ningxia, and Shanzxi), over 400 million people are threatened, with a desertification rate of 2,400 square kilometers per year and desertified lands reaching 2,620,000 km^2.

TABLE 1. Population changes in Central Asia over the past few decades.

Countries	From	Population (1,000)	To	Population (1,000)
Kazakhstan	1922	5,377	2008	15,341
Turkmenistan	1922	903	2008	5,180
Uzbekistan	1922	4,363	2008	28,268
Kyrgyzstan	1922	883	2008	5,357
Tajikistan	1922	965	2008	7,212
Afghanistan	1953	8,573	2008	32,728
Mongolia	1940	750	2008	2,996
China	1949	512,740	2000	1,330,000

The following are a few examples of recent environmental degradation in Central Asia. In Kazakhstan, many lakes have dried up as a result of increased water withdrawal along the rivers and streams since 1950s. In the Turpan basin of China, intensive cultivation and conversion from natural grasslands to irrigated cropping agriculture systems in the late 1960s led to a complete dry-up of the Turpan River. Agricultural intensification and grassland overgrazing subsequently resulted in about 80 km^2 of deserts. During the same period of time, Mongolia experienced similar environmental issues. Due to overgrazing, military occupation from the former Soviet Union and Mongolia, and forced settlement of nomadic peoples, the ecological condition especially in the Eastern Mongolia was seriously degraded and villages were abandoned.

4. Climate change contributes to environmental problems

Although social, political and economic pressures are responsible for substantial transformations of the lands that have altered the food productivity of the region, climate change is becoming a major driver of altered ecosystem productivity as people respond to increasing climate variability (e.g., Lioubimtseva et al., 2005). Changes in the large-scale climate circulation due to enhanced greenhouse gases can bring about land use change, which may significantly alter food production systems (Figure 3). However, determining the appropriate mitigation and adaptation strategies to cope with both recent and projected climate changes is particularly critical in this region for several reasons. First, this region is comprised primarily of arid and semi-arid ecosystems that are thought to be most vulnerable to climate change and variability. Under the current climate conditions, most agricultural lands (including grasslands and croplands) in the region are less productive than ecosystems in temperate regions due to soil and climate patterns. Water in this region is one of the most critical factors because precipitation is very scarce and reduction in precipitation will surely impact agricultural productivity. Second, many nations of the region rely largely on natural rainfall (as opposed to irrigation) for their agricultural production. Droughts pose a significant threat to the food security of the region. Furthermore, increases in population, especially in India and the western part of China, are placing additional demands on the existing food resources of the region.

As the region's traditional agriculture was rainfed, regional climate variability is certainly a major concern for food security, as a more pronounced shift in the quality of cropland is predicted in developing countries (Schmidhuber and Tubiello, 2007; Fischer et al., 2002). Even in areas where irrigation is used in modern agriculture, reduced precipitation and changes in precipitation pattern have significantly affected the region's water resources. The drying out of the Aral Sea is believed to be due both to the increased water withdrawals from the two major incoming rivers (Syr Darya and Amu Darya) and reduced rainfall in the region over the past 50 years (Figure 4) (Lebed et al., this book).

Yet little research has been conducted regarding the nature of climate impact on ecosystem productivity. In particular, there is a paucity of research on how agricultural ecosystems respond to changes in climate and how changes in regional climate impact agricultural ecosystems, especially their soil carbon, soil fertility, and greenhouse gas emissions. To lessen vulnerability of these developing countries, it is imperative to address the question: What type of agricultural management practices can be adapted in anticipation of future climate changes in order to lessen vulnerability of these countries?

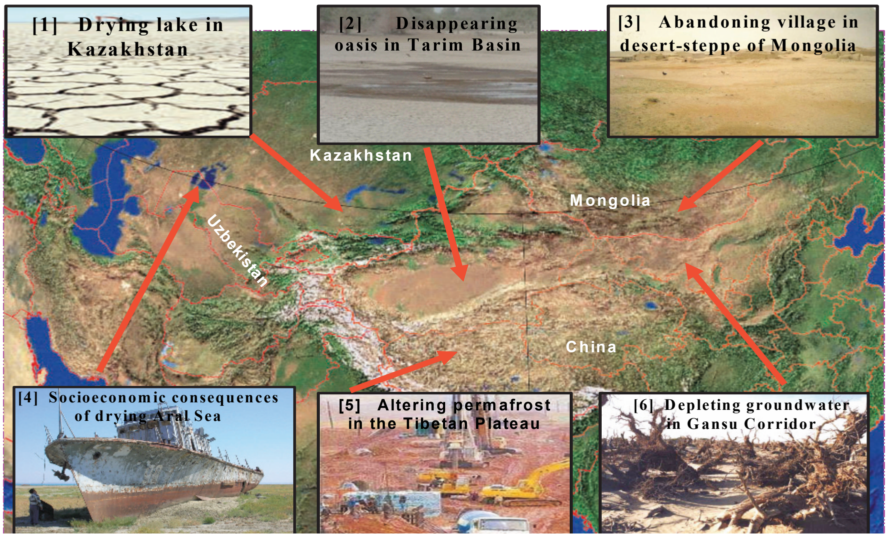

Figure 3. Environmental issues across all Central Asia and Asia (modified based on Z. Feng at Lanzhou University, China).

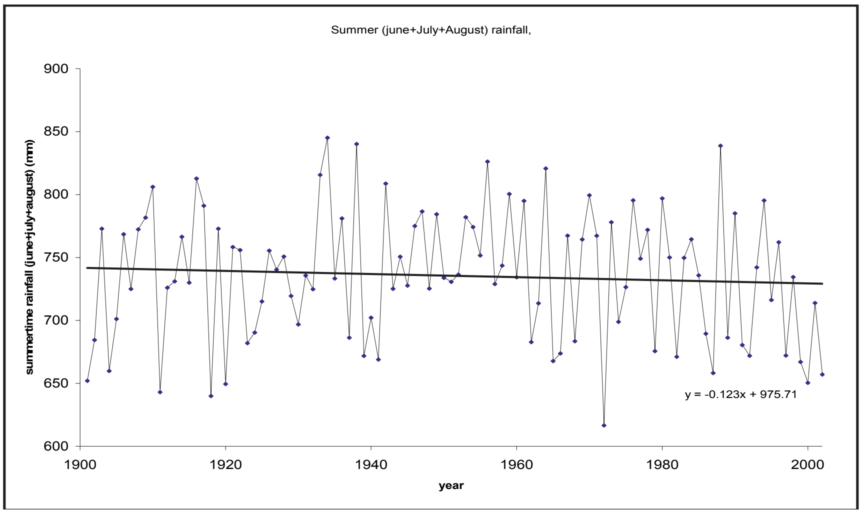

Figure 4. Summer precipitation totals in Central Asia in the past 100 years.

5. Socioeconomic consequences are unprecedented

The socioeconomic consequences of the regional environmental change that may be significant include local economy, food security and regional stability. As is well known, the main contribution to the regional economy comes from agriculture. Increasing complications related to water deficiency, soil salinization, desertification of the land and climate change are rendering the agricultural sector ineffective.

In addition, environmental changes may also cause health-related problems. All these changes can become reason for increasing unemployment and emigration among younger segments of the population.

Finally, the environmental problems in the Central Asian region could contribute to growing religious extremism via deepening social and economic problems. In many cases, religious extremists use unemployment and substandard living conditions as tools to enlarge their community. Therefore deep ecological problems of the region can be considered as an indirect threat for regional security, the slow progression of which could lead to serious complications. This threat underscores the need for investigation of environmental problems of the region on the basis of a complex approach taking into account all the impacts of this problem.

6. Research needs

There is an urgent need to develop adaptation strategies to cope with environmental changes, particularly to deal effectively with water shortages in the region. However, sound and practical adaptation strategies can be developed only when sufficient environmental information is available and the root causes of the environmental problems are fully understood and quantified. There are both conventional and geospatial tools available, but their usefulness in addressing environmental issues needs to be objectively assessed. Satellite imagery, for example, can provide a large scale assessment of water quantity (both in the form of freshwater and snows/glaciers) and, therefore, can be used to monitor water resources for irrigation planning. Operational use of such information requires an infrastructure for image processing and interpretation. Improved irrigation systems are available to reduce evaporative water losses, such as drip irrigation systems, but they need to be fully assessed in terms of adaptation to different regional water chemistry and economic viability. New crops more tolerant to droughts of short duration are potentially available, but yield productivity and economic profitability in Central Asia needs to be assessed. With globalization, economic prosperity and food security of the region must be analyzed in the global context in order to develop a sound sustainability strategy. Furthermore, in anticipation of future climate change, either in the form of increased climate events such as droughts and floods, or in the form of increasing water scarcity, adaptation strategies for viable agriculture need to developed. Prototyping such a strategy at a smaller scale will be important for large scale implementation of the strategy. An iterative adaptation strategy should be prototyped, modified, implemented and fully assessed.

Case studies remain necessary demonstration projects that will serve as models to mitigate or adapt environmental changes at scales that matter. Collectively, these small scale projects and efforts can eventually be aggregated to achieve regional sustainability.

Acknowledgements

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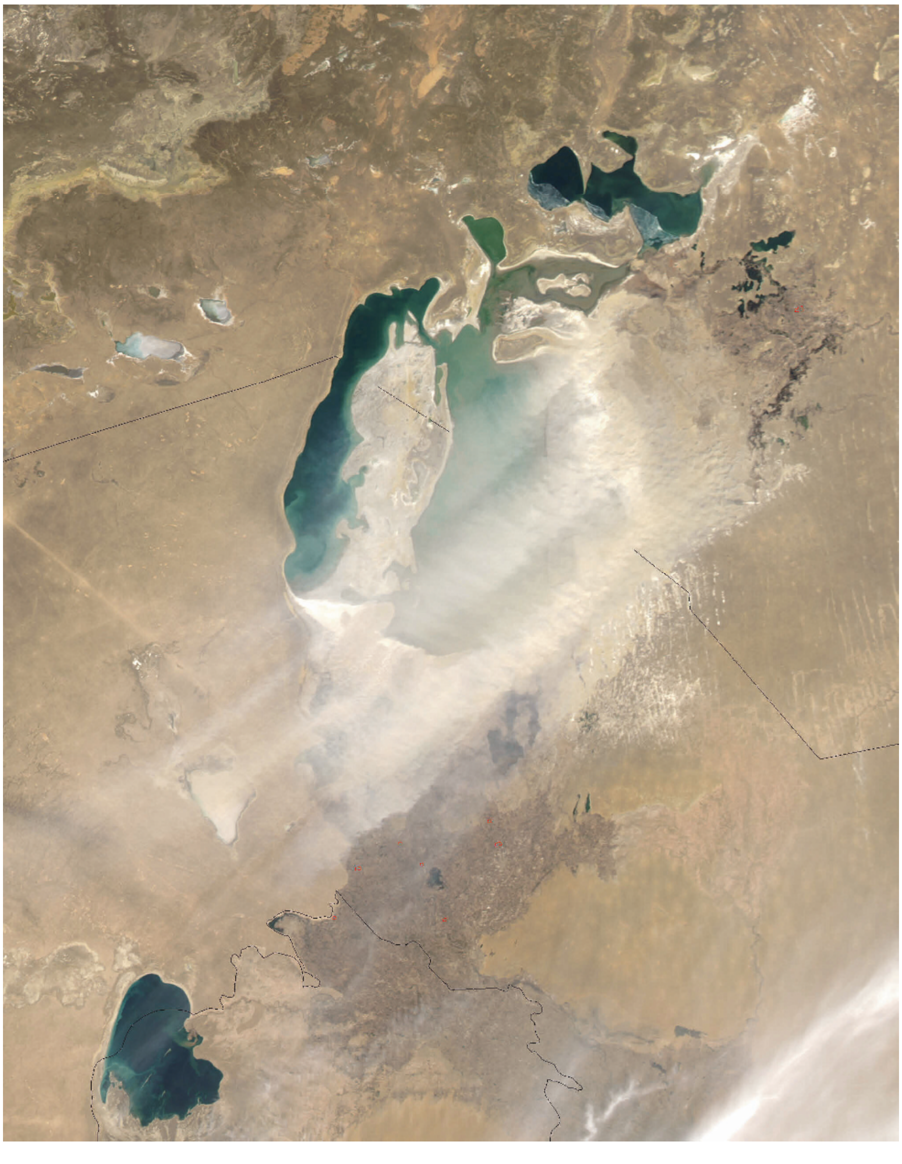

MODIS image of a dust/salt storm on the Aral Sea on April 8, 2003 (natural color).

MODERN PROBLEMS IN USING, PROTECTING, AND MANAGING WATER AND LAND RESOURCES OF THE ARAL SEA BASIN

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Abstract. Problems of using, monitoring, managing, and protecting water resources of the Aral Sea basin are pressing because of the extremely limited nature of these resources, increasing pollution levels, and the threat of a shrinking – and gradually disappearing – Aral Sea. Results from the author's long-term research on monitoring and protection of water of the main rivers – the Amu Darya and the Syr Darya – are provided. The sources of pollution and problems in protecting water and land resources of the Aral Sea basin are discussed. The problems of return waters and underground water formation and opportunities for their use are also discussed. The results of research on migration and distribution of polluting substances (heavy metals) in the main rivers of the Aral Sea basin are considered.

Keywords: Aral Sea basin, water and land resources, pollution, return waters, underground waters, monitoring, heavy metals, form migration

1. Introduction

The Aral Sea basin includes five Central Asian countries (Figure 1). The southern part of Kazakhstan and the Syr Darya basin are also included in the Aral Sea basin. The basic volume of river water resources is formed in mountain systems and concentrated in trans-border rivers that are used jointly by the Central Asian states. The main portion of the Amu Darya's flow (about 83%) is formed in the territory of Tajikistan; it travels through Uzbekistan, on the border with Afghanistan, then through the territory of

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Figure 1. The Aral Sea basin.

Turkmenistan and again crosses the territory of Uzbekistan before flowing into the Aral Sea. About 8% of the Amu Darya's flow is formed in the territory of Afghanistan and about 3.5% in the territories of Iran and Turkmenistan. Approximately 80% of the basic flow of the Syr Darya basin is formed in the territory of Kyrgyzstan. From there the Syr Darya travels through the territories of Uzbekistan and Tajikistan and crosses into the region of Kazakhstan, flowing into the Northern Aral Sea. Sources feeding the river are snow (78%), glaciers (14–16%), and rain (3.10%). More than 90% of the river waters of the Aral Sea basin are used for irrigation 1(Ososkova et al., 2000). Flows from the largest rivers of the region – the Syr Darya and the Amu Darya – are used extensively.

2. Land resources of the Aral Sea basin

Out of a total of land resources of about 154.9 million hectares, some 59.1 million hectares are considered to be cultivable, of which only about 10 million hectares are actually used (Table 1). Distribution of arable land resources among the countries reveals a great inequity, characterized by good land availability in Kazakhstan and in Turkmenistan and conditions of land scarcity for the three other countries. Only about 7.9 million hectares are irrigated (or only 5.1% of the total territory of the Aral Sea basin). Cotton still remains one of the most important crops, although between 1990 and 2003 its share of irrigated agriculture decreased from 45% to 25%. In the same period, the area under cultivation for cereals (i.e., wheat, rice, maize, and others) increased from 12% to 77%. Wheat became the dominant crop in the region, which covers about 30% of its total irrigated area. Fodder crops in 1998 occupied only 19.6% of the total irrigated area, compared to 27.4% in 1990 (Lal, 2007; Qushimov et al., 2007).

All of the Aral Sea basin countries now have land resource problems of desertification, degradation, and salinization. The major environmental problem in the Aral Sea basin, with regard to sustainability, is the increasing salinization of irrigated soils. Combating this salinization problem should be a top priority. Irrigated lands of Turkmenistan and Uzbekistan are subject to the greatest risks of salinization. More than 50% of the irrigated lands of Uzbekistan are subject to various degrees of salinization. Salinization, water logging, overgrazing, irrigation erosion, cutting down bushes, and other anthropogenic factors of land degradation are problems common in the states of Central Asia (Lal, 2007; Qushimov et al., 2007; Kulmatov and Zokirov, 1998).

The countries of the Aral Sea basin do not have systems that monitor land conditions. Methods of monitoring ongoing processes of land degradation should be adopted and improved in order to develop recommendations for its reduction. Cooperation among the countries of the region in the area of land degradation and desertification should be developed.

TABLE 1. Land resources in the Aral Sea basin.

Country	Area of the country	Cultivable area	Cultivated area	Actual irrigated area
	ha	ha	ha	ha
Kazakhstan[a]	34,440,000	23,872,400	1,658,800	786,200
Kyrgyzstan[a]	12,490,000	1,257,400	595,000	422,000
Tajikistan	14,310,000	1,571,000	769,900	719,000
Turkmenistan	48,810,000	7,013,000	1,805,300	1,735,000
Uzbekistan	44,884,000	25,447,700	5,207,800	4,233,400
Aral Sea basin	154,934,000	59,161,500	10,036,800	7,895,600

[a]Only provinces in the Aral Sea basin are included

3. Water resources of the Aral Sea basin

The total mean annual flow of all rivers in the Aral Sea basin (a location with an area of 1,550,000 km^2) is estimated at about 116 km^3. This amount comprises the flows of both the Amu Darya, at 79.4 km^3/year, and the Syr Darya, at 36.6 km^3/year. In accordance with flow probabilities of 5% (high wet years) and 95% (dry years), the annual flow ranges from 109.9 to

58.6 km^3 for the Amu Darya, and from 51.1 to 23.6 km^3 for the Syr Darya, respectively (Dukhovny and Stulina, 2001).

The total length of the irrigation network was: inter-farm – 47.75 thousand km, on-farm – 268.6 thousand km. The total amounts of drainage wells are: 865 thousand km, total length of collector-drainage network; 191.9 thousand km, including subsurface; and, 47.9 thousand km.

On Figure 2, distributions of long-term annual flows of both the Amu Darya and the Syr Darya are shown. Apparently from data figures, no significant fluctuations are observable on long-term flows of river waters. The flows of river waters depend on melting snow and ice in the mountains and on precipitation in the low lying mountain areas, as well as on underground water resources.

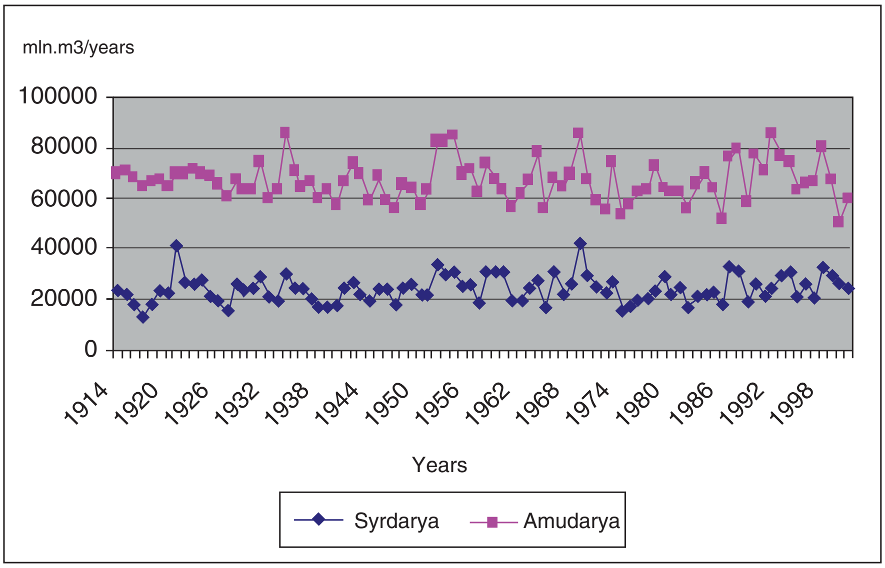

Figure 2. A long-term data annual flow of the rivers.

Long-term data about distribution of water resources in the countries of the Aral Sea basin are presented in Table 2. Among the countries of the Aral Sea basin, Tajikistan has the greatest quantity of water resources eventually flowing into the Amu Darya basin, and Kyrgyzstan has the greatest quantity flowing into the Syr Darya basin. Countries having the lowest quantities of water resources are Turkmenistan and Uzbekistan. Hence there are now some disagreements over sharing water resources between the countries of the Aral Sea basin. Kyrgyzstan and Tajikistan are interested in using river waters for generating electric power in the winter season, whereas Uzbekistan, Turkmenistan, and Kazakhstan each use water resources in the summer time, primarily to meet irrigation needs.

TABLE 2. Surface water resources in the Aral Sea basin (mean annual runoff, km^3/year).

Country	River basin		Total Aral Sea basin	
	Syr Darya	Amu Darya	km^3	%
Kazakhstan	2.516	–	2.51	2.2
Kyrgyzstan	27.54	1.65	29.19	25.2
Tajikistan	1.005	58.7	59.73	51.5
Turkmenistan	–	1.40	1.405	1.2
Uzbekistan	5.56	6.79	12.35	10.6
Afghanistan and Iran	–	10.8	10.81	9.3
Total Aral Sea basin	36.62	79.4	116.02	100

Data about use of water resources in various branches of the economies in the countries of the Aral Sea basin are shown in Figure 3. The greatest quantities of water resources consumed for agriculture are used by Uzbekistan, then by Turkmenistan. The majority of water resources in irrigation are used in the cultivation of cotton and wheat.

For the countries of the Aral Sea basin, water deficits and pollution of water resources are characteristic problems. The main sources of pollution of superficial and river waters of the Aral Sea basin are the waters returning after irrigation of agricultural crops.

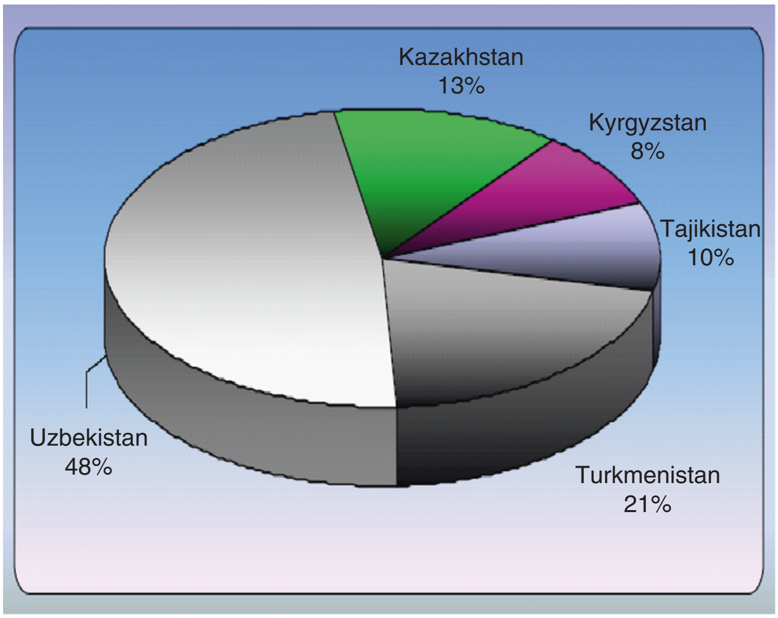

Figure 3. Use of water in agriculture at the Central Asian Republics.

4. Agriculture of Uzbekistan

In the Uzbek republic, levels of water consumption in various industries (e.g., in mountain-metallurgical, fuel and energy, gas and oil extraction and processing, aircraft and motor industries, and manufacturing mineral fertilizers) and in agriculture are high. From 7 million hectares of irrigated lands in the Central Asian region, about 60% (i.e., 4.2 million hectares) is found in Uzbekistan. Conditions of Uzbekistan have special values with irrigated lands. Occupying only 15% of all farmlands, irrigated farms contribute more than 95% of all agricultural production. However, the sizes of irrigated lands in the republic are limited by the presence of water in sources for irrigation, which are already exhausted at present. More than half (51%) of irrigated farmlands are salted, 31% are weak salted, 15% are average salted, and 5% are over salted. In Uzbekistan, more than 60% of the land is used for agricultural needs.

In order to generate high levels of crop production – especially of cotton – during the Soviet era, vast quantities of mineral fertilizers and pesticides were used. In Figure 4, data about the use of pesticides in the agricultural sector of Uzbekistan are provided. On all irrigated lands in Central Asia, pesticides and fertilizers were used to in amounts that far exceeded the norms of the former Soviet Union. For example, in Uzbekistan an average of 147 kg of fertilizers per ha were used in agriculture. The total amount of pesticides used in Uzbekistan was between 30–35 kg/ha, almost 25–30 times higher than in the Soviet era. After independence, the purchase and use of pesticides in agriculture were considerably reduced. The reasons for the decline are the high costs of pesticides.

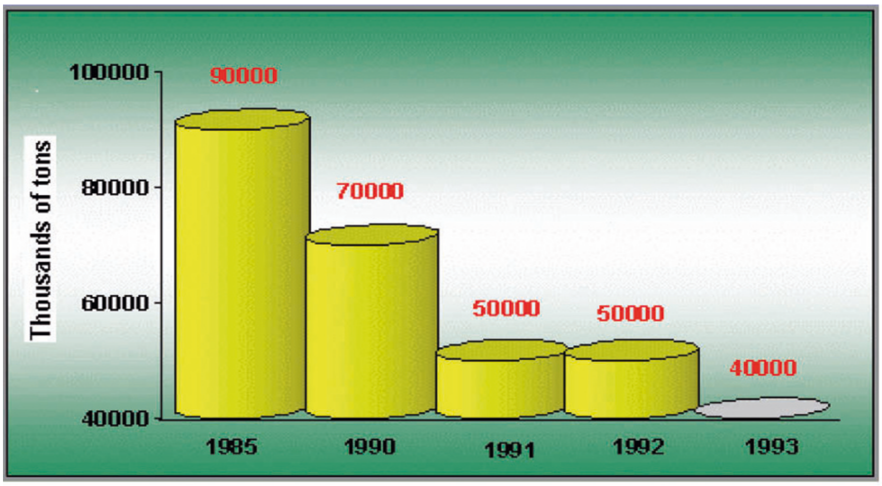

Figure 4. Use of pesticides.

5. Quality of water of the Amu Darya

For a number of years, we investigated water quality of both the Amu Darya and the Syr Darya. Analytical works analyzing the composition of river waters are carried out in the Institute of Nuclear Physics' laboratories of the Academy of Sciences of the Republic of Uzbekistan and Uzgidromet. Concentrations of more than 30 components, including heavy metals, are determined (Kulmatov, 1994, 2004; Kulmatov et al., 1998). Concentrations of phenols, iron, and zinc, and general mineralization in the lower reaches of the Amu Darya and the Syr Darya have been 1.3–4 times higher than the maximum allowable concentrations (MAC). Mean annual mineralization of the Amu Darya increased almost twice in the last 30 years. The Amu Darya and its tributaries are characterized by low COD (chemical oxygen demand) and BOD (biochemical oxygen demand) values compared with levels that are otherwise typical for rivers in arid zones. Therefore, the average BOD value gradually decreases from upstream to downstream (Figures 5 and 6).

The oxygen mode of the river in 2006 was satisfactory; concentrations of dissolved oxygen were on average at level 11.7 mg O/L – levels that corresponded to ones recorded in the previous year. In Uzbekistan, waters of the Amu Darya act with small contents of organic substances. In the range of Termez city, the value of COD on average has made 4.5–28.6 mg O/L, making on the average on the river 16.9 mg O/L. An essential fluctuation depending on a hydrological mode was not observed.

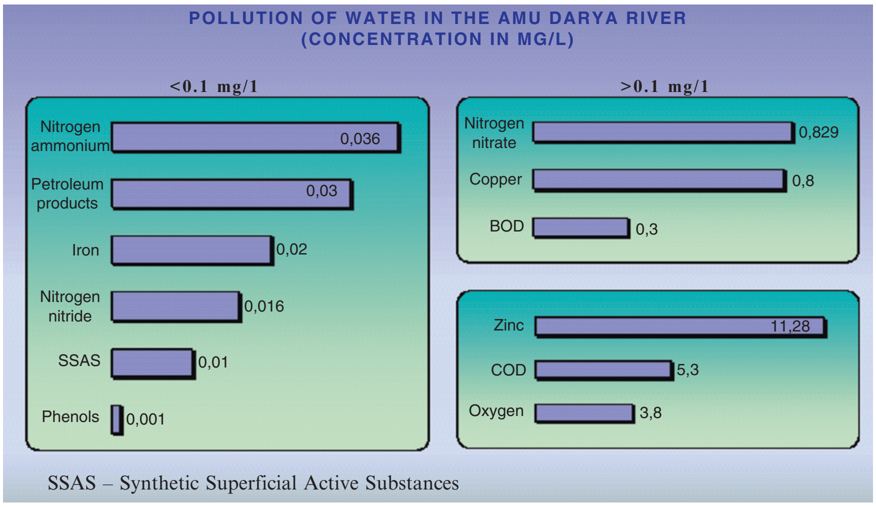

Figure 5. Contents of pollutants in the Amu Darya.

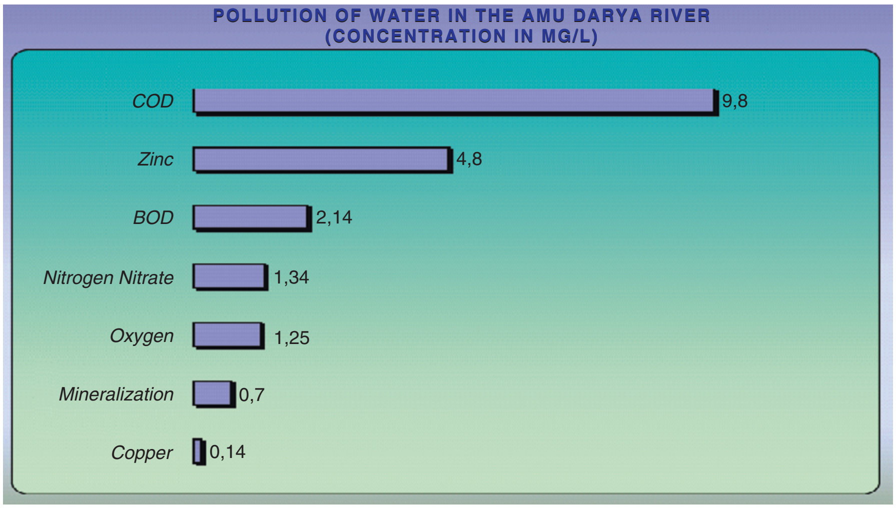

Figure 6. Contents of pollutants in the Amu Darya.

The level of pollution of the river by petroleum is low, on the average 0.07 mg/L (1.4 MAC), DDT (Dichlorodiphenyltrichloroethane) and its metabolites are not found out. The level of pollution of the river in 2006 has increased in 1.1–1.3 time. The contents of ammonium, nitrates and nitride nitrogen are low. Contents of alpha-HCH (Hexachlorocyclohexane) –0.004 mkg/L (0.4 MAC), gamma HCH – up to 0.002.

6. Sources of pollution of the Syr Darya

In the Syr Darya basin, irrigated land totals about 2 million hectares, and channels with a total volume of water fence of 23.12 km^3/year are constructed for irrigation. On needs of irrigation of water fence from the river has increased from 70% in 1960 up to 90% in 2006. The extent of main and inter-economic collectors makes 13,690 km.

The Syr Darya basin is located in an area that accommodates for large industrial operations, with waste water rendering an influence on the overall quality of water resources in the basin, to which concern: ON “Electrokhimprom,” Alti-Arykoil refining factory, lime factories, and urban clearing structures. In the Syr Darya basin, there were six Uzbek regions: Andizhan, Namangan, Fergana, Tashkent, Dzhizak and Syr Darya, and wastewater is dumped into the Syr Darya and its inflows. The majority of Syr Darya waters are used for irrigation (Figure 7).

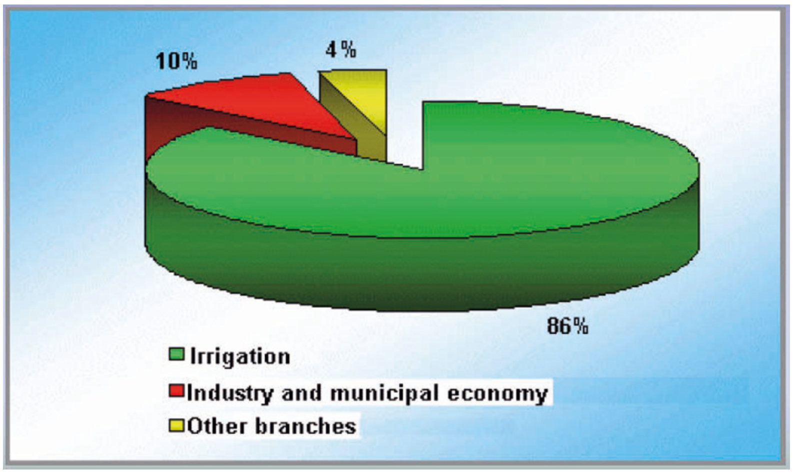

Figure 7. Use of water in various branches of national economy in the Syr Darya basin.

7. Quality of water of the Syr Darya

The oxygen levels in 2006 were satisfactory, with concentrations of dissolved oxygen at levels of 10.35 mg O/L – levels that corresponded to those of the prior year, as well. In the currents of the river, the contents of organic substances (on COD) varied within the limits of 8.1–16.8 mg O/L. Waters are most polluted by organic substances, in ranges below Bekabad city and Nadejdinsky settlement, where the maximum values of COD were 28.1 mg O/L and 33.3 mg O/L, accordingly.

The contents of phenols in the currents of the river varied a little and were on average 0.001 mg/L (1 MAC) – corresponding to levels of the last year. Pollution of the Syr Darya by petroleum significantly increased, but it did not exceed MAC –0.04 mg/L (0.8 MAC). The contents of copper have not changed, and the contents of zinc and chrome in comparison with levels from the previous year increased 1.2–1.3 times and made 0.8 mkg/L (0.8 MAC), 5.6 mkg/L (0.6 MAC) and 1.4 mkg/L (1.4 MAC) accordingly. The presence of HCH isomers was marked at a level of 0.002 mkg/L (0.2 MAC), DDT and its metabolites were not found. Data on pollution of waters of the Syr Darya are given in Figures 8 and 9.

Water of the river increased mineralization –1137.8 mg/L (1.1 MAC), that on 66.2 mg/L is higher than in the previous year. Chemical structures in all phases of the hydrological mode, water concerns to chloride class (seldom sulphate), group of sodium or calcium. Therefore, water quality at the bottom of currents of the Amu Darya and the Syr Darya worsened.

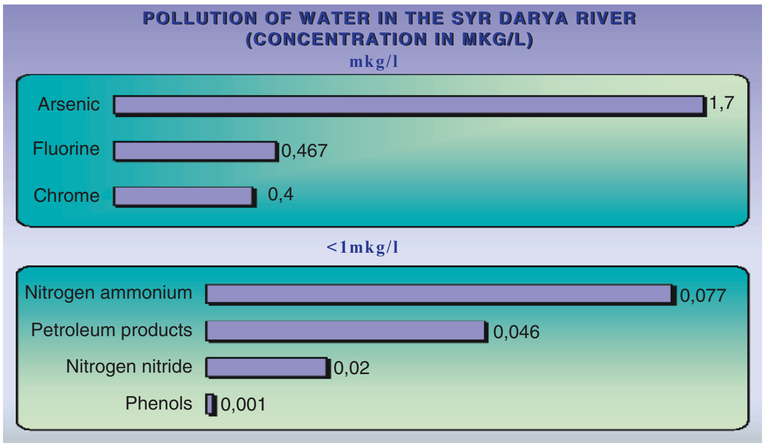

Figure 8. Contents of pollutants in the Syr Darya.

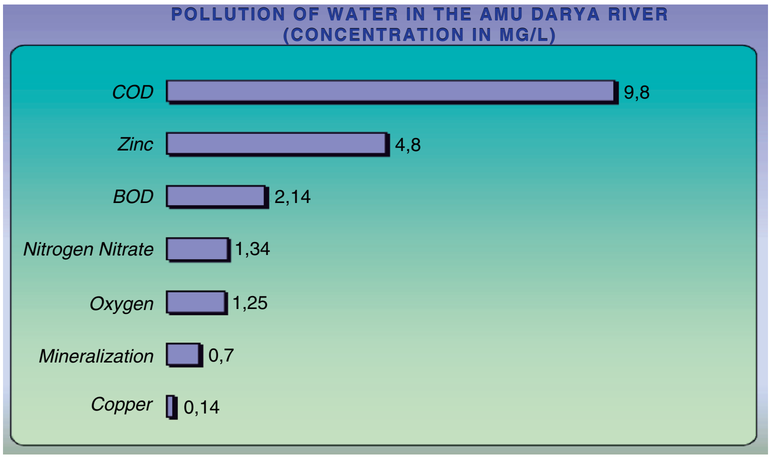

Figure 9. Contents of pollutants in the Syr Darya.

The salinity level increases in time and along the river, especially in the middle and lower reaches of the river. At the end of the 1960s the mineralization of water did not exceed 1.0 g/L, even in the lower reaches. Now it varies from 0.3–0.5 g/L the upper reaches to 1.7–2.0 g/L the lower reaches. The highest values are recorded in March and April in the upper reaches, and around May in the lower reaches. An explanation for these differences could be the leaching procedures in irrigated areas. There is an intensive drainage and salting of grounds in deltas of these rivers, deep degradation of ecological systems, flora, and fauna.

8. Return waters

The main sources of environmental pollution of river waters of the Aral Sea basin are "return waters." The annual mean values of return flows, consisting of drainage and wastewater from irrigation, industry, and municipal users have varied between 28 and 33.5 km^3. Levels are about 13.5 to 15.5 km^3 annually in the Syr Darya basin, and about 16 to 19 km^3 in the Amu Darya basin (Dukhovny and Stulina, 2001).

In Figure 10, data on variations in the total amount of collector-drainage waters on the Amu Darya on years are cited. The mineralization of return waters changes over a wide range. If in the upstream the rivers the mineralization of return waters makes 2–5 g/L, in a lower reaches 5–10 g/L.

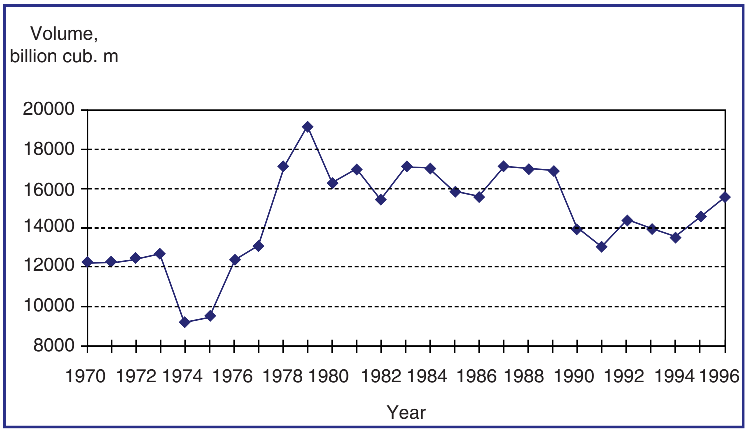

Figure 10. Drainage and wastewater variations in the Amu Darya basin.

Drainage water involves two components: the surface component consists of the outflow from irrigated fields, losses from the irrigation network, and water pumping from the vertical drainage system from irrigation networks that reach the collector-drainage system.

The return flow is an additional water resource for irrigation. However, it is a main source of the water and environmental pollution because of its high mineralization. About 95% of the total volume of return flow is from irrigation drainage water and the rest is from industrial and municipal wastewater.

The quality of the drainage effluent depends on the location of the irrigation scheme within the river basin (upper, middle, or lower reaches) and the leaching requirements of the irrigated area. It also depends on the use of agro-chemicals. The local salt mobilization is determined in part by the type of the drainage system (open, subsurface or vertical), seepage, drain spacing, and drain depth. The poor quality creates limitations for the re-use of drainage water, especially for irrigation. Only about 15% of total return flows are re-used and more than 55% returns to rivers. About 30% end up in natural depressions, from which the water evaporates. All countries of the Aral Sea basin have problems of using, management and clearing of return waters.

9. Underground waters, Uzbekistan

In Uzbekistan, total stocks of underground waters are estimated at 18.44 km^3 with high quality –11.53 km^3 (Table 3). For sustainable use of the stocks, withdrawals of 6.35 km^3/year are suitable. Most underground waters are concentrated in flat areas in lenses along rivers and large irrigation channels, and they are closely connected with superficial water flows, therefore increase of stock of underground waters results in reduction of superficial drain on size of selection. The underground waters of the region are formed from the accumulation of precipitation filtration, filtration of reservoirs, riverbeds, channels, lakes, and water from irrigated lands. The latter is significant. Uzbekistan has sufficient volumes of quality underground water resources. Underground waters are a basic source of drinking water for Uzbekistan.

TABLE 3. Underground water resources.

Ground water resources in the basin of the Aral Sea (km^3/year)			
State	Evaluation of regional resources	Exploitable resources approved for use	Available to use
Kazakhstan	1.85	1.22	0.173
Kyrgyzstan	0.86	0.67	0.291
Tajikistan	6.65	2.2	0.975
Turkmenistan	3.36	1.22	0.42
Uzbekistan	18.45	7.79	6.96
Aral Sea basin	31.17	13.11	8.07
Syr Darya basin	16.42	7.43	4.76
Amu Darya basin	14.75	5.68	3.31

10. Research of the law of distribution of heavy metals in river waters

During 1980–2006, we investigated some laws of spatial-time distributions of heavy metals in the waters of the largest rivers of Central Asia – the Syr Darya and the Amu Darya. The basic purpose of executing this long-term research was to study the conditions and mechanisms of the formation of heavy metals composition of river waters, and to estimate the anthropogenic contribution on the basis of study and estimation of the laws of migration and distribution of heavy metals in the main rivers (Kulmatov, 1994, 2004; Kulmatov et al., 1998). The basic quantity (more than 50%) of heavy metals, such as mercury, chrome, antimony, zinc, and cadmium, in the rivers of the region migrates in dissolved forms, which is necessary to take into account in estimating pollution and migration of metals in these rivers. On the other hand, less toxic elements like iron, europium, lanthanum, and cobalt migrate basically in un-dissolved form.

In river waters of the arid zone, the contents of the majority of heavy metals (Hg, Cr, Sb, Co, Fe, Zn) is 3–5 times higher in comparison with averages found global data. This rather high content of heavy metals in the river waters of the arid zone caused by the landscape, geo and biochemical features, and the lythology-mineralogical composition of the type of ground in the top ranges. The conditions of the arid climate, and also alkaline reaction of ground and types, which are characteristic for the entire basin, advance a rather high mobility of Hg, Zn, Cd, Sb, Cr, Co, and other elements in the river waters of arid zone that urgently demand a more detailed study as to their forms of migration in researched waters. With the development and application of complex physical and physical-chemical methods, forms of migration of heavy metals in river waters of the Aral Sea basin have been investigated for the first time. For these purposes, methods of ultra-filtration, electro dialysis, ionic exchange, and extraction of separate forms of elements were developed (Kulmatov, 1994, 2004).

Quantitative determination of the contents of heavy metals in the divided fractions carried out with application of radio analytical methods. In Table 4,

TABLE 4. Migration forms of some heavy metals in the river waters (%).

Sample collection location	Migration forms	Sm	U	Au	Cr	Sb	Co	Hg	Zn	Fe	Sc
Syr Darya range of Bekabad	Suspended matter > 0.85 mk	49.4	6.4	5.8	6.9	45.6	23.4	59.1	4.2	28.3	84.0
	>0.12 mk	2.8	3.3	2.0	2.1	8.9	1.1	1.3	2.8	2.1	3.4
	Colloid +	2.1	1.9	–	3.8	–	1.1	4.4	5.1	17.7	–
	Colloid	6.3	5.0	12.5	2.9	5.2	1.3	3.5	3.1	11.3	–
	Neutral	34.7	50	19.7	–	–	6.9	–	19.9	16.7	3.6
	Kation	3.5	14.5	7.1	47.1	–	30.6	6.4	60.0	21.7	7.5
	Anion	1.3	18.6	53.0	37.2	39.8	35.8	25.4	1.1	2.2	1.6
Amu Darya range of Termez	Suspended matter > 0.85 mk	44.1	6.9	5.8	1.8	23.5	14.3	31.4	11.5	8.3	62.1
	>0.12 mk	3.6	1.2	1.4	1.1	9.1	3.2	2.6	1.9	0.5	0.8
	Colloid +	0.9	2.5	4.9	5.3	11.5	2.8	11.7	4.2	20.0	–
	Colloid –	4.6	1.7	9.0	2.7	20.8	2.3	7.3	1.3	13.0	–
	Neutral	20.2	20	15.6	8.1	–	5.9	15.0	17.4	7.7	11.4
	Kation	8.9	22.7	9.7	49.4	–	23.2	13.0	59.0	42.7	8.3
	Anion	17.7	5.2	53.0	31.9	35.4	48.0	18.9	4.2	7.4	16.5

data about forms of migration of some heavy metals in water of the Amu Darya and the Syr Darya are presented. It has been established that, in river waters of the Aral Sea basin, heavy metals migrate in aggregate weighed, colloid, and ionic-soluble forms. Correlations between them change depending on the type of water and the physical-chemical properties of the elements. The content colloid forms of heavy metals fluctuate between 5% and 20%. Mercury migrates in anionic, neutron, and colloid forms (Kulmatov, 1994; Kulmatov et al., 1998). In the river waters of the arid zone, we thus observed a high content of inorganic components in comparison with that organic content.

On the base of experimental data and thermodynamic modeling, we established that in distinction with the nature of water in humid zones, in the migrations of heavy metals in surface waters in arid zones, inorganic ligands (OH^-, SO_4^{2-}, Cl^-) play a primary role. Results received about the forms of heavy metals may be the basis for developing technologies of water preparation for water-pipe stations in researched rivers and for effective clearing of water of heavy metals.

11. Water resources management of the Aral Sea basin

After the disintegration of the Soviet Union, there were certain difficulties in water resource management in the Aral Sea basin. The basic quantity of waters draining into the rivers of the Aral Sea basin is formed in Tajikistan, Kyrgyzstan, and Afghanistan. However, the main consumer of the waters of the Aral Sea basin is Uzbekistan. Therefore, there are now some disagreements regarding sharing and management of water resources in the Aral Sea basin. It is also necessary to take into account in the future water fence from Afghanistan.

12. International cooperation in the area of environmental protection

The above-stated scales and complexity of ecological problems require a complex and diversified approach and significant internal resources, which are rather limited under the conditions of transition economies and formative market relations. For this reason, significant roles are played by external financing, which should concentrate on matters of global and regional problems of environmental protection and the rational use of natural resources.

Uzbekistan has joined with the majority of states in signing to International Conventions on environmental and sustainable development and the protocols of development in these documents, it has approved the decision of the European conferences at the level of the ministries of environmental protection, and it has signed a number of international agreements for cooperation in the area of environmental protection. Hence, for decisions of complex use, management, and protection of water resources of the region, it is necessary for active participation in the international community, in related organizations, and with experts. Maintaining the important interests of and participation in the decision-making processes of dealing with water problems in the Aral Sea basin by those economically advanced countries of the world (e.g., the US, Germany, Japan, and others) is also important.

13. Summary

For all countries of the Aral Sea basin, prevention of desertification of land resources is important. Key initiatives must include the following:

- Development of scientific, practical and engineering/design initiatives directed towards the conservation, rational use, and protection of water resources of the Aral Sea basin are needed.
- Development of water monitoring systems in the Amu Darya and the Syr Darya basins, and installation of modern equipment for measuring the volume and quality of river waters (*Concentration of phenols, iron, zinc and the mineralization in the lower reaches of the Amu Darya and the Syr Darya has been 1.5–4 times exceeded MAC*).
- The main source of pollution of river waters in the Aral Sea basin is the water returning after irrigation of agricultural lands. Therefore, realization of research and engineering-design work on re-use and treatment of collector-drainage waters is necessary.
- Dissolved forms of toxic metals migrate in the form of free ions and complexes with inorganic ligands in river waters of the Aral Sea basin, such as: chlorine, sulphates, hydroxyl ion, and others. Data obtained should be used to develop effective methods of treating river waters for drinking needs.
- Perfection and development of economic mechanisms in the sphere of water distribution and use at national and regional levels is needed.
- To strengthen interactions between NGO, mass media, governments, international funds, and organizations in the decision-making processes involving water-land problems.

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USING SATELLITE REMOTE SENSING TO STUDY AND MONITOR THE ARAL SEA AND ADJACENT ZONE

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Abstract. The Aral Sea is a large, terminal lake in Central Asia that has undergone rapid desiccation accompanied by severe environmental degradation. This paper summarizes the key parameters of this phenomenon and discusses the use of satellite remote sensing to study and monitor the Aral Sea and its surrounding area.

Keywords: Aral Sea Central Asia, remote sensing, satellite images, GIS, lakes, water, Kazakhstan, Uzbekistan

1. Introduction

Satellite remote sensing technologies, developed so rapidly since the early 1960s, have proved amazingly useful to gather and analyze data on our planet and its condition. Their most valuable attributes in this regard are (1) frequent and regular coverage, (2) a variety of resolutions ranging from several meters to several kilometers that allows showing limited areas in great detail or large swaths in much more generalized form, (3) multiple spectral bands each of which is sensitive to different reflectances and emissions from the earth's variable surfaces (4) and since satellite sensors record band data in digital format (0s and 1s), these may be combined and manipulated by appropriate remote sensing and GIS software to provide information about the geologic, geographic, hydrologic, biologic, and human environment not discernable from photography or ground observations.

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Satellite remote sensing data have aided greatly in understanding critical environmental/ecological problems and developing sound, scientifically based strategies for their mitigation.

An instructive example is the so-called Aral Sea problem. The Aral Sea, a large lake in Central Asia, has endured rapid desiccation since the 1960s owing to diminution of the flow of its two influent rivers, primarily owing to irrigation withdrawals. This has had severe negative impacts on the environment as well as humans. Given the large spatial dimensions and complicated nature of the Aral Sea problem, remote sensing (and its allied technology of GIS) has been successfully employed to study its myriad parameters and to provide a stronger scientific basis for developing appropriate alleviatory measures.

In this paper, I shall first review the basic nature and key parameters of the "Aral Sea Problem." This will be followed by a discussion of the use of remote sensing (and to a lesser degree, GIS) to better understand this issue and to contribute to its mitigation. There is no claim here to comprehendsiveness. The efforts described are ones I know about or in which I have participated. There, no doubt, are others of which I am not aware. Furthermore, I limit my spatial purview to the sea proper and its immediately adjacent region. I shall not discuss, for example, the major efforts that have been (are) focused on creating sophisticated GIS systems and analytic/predictive models of the entire Amu and Syr Darya river systems (see http://water.freenet.uz/). The intent in this paper is to give a broad overview of the topic; detailed discussion of the specifics of particular remote sensing and GIS techniques will be avoided.

2. The Aral Sea problem

2.1. LOCATION, NATURE, AND HYDROLOGY OF THE ARAL SEA

The Aral Sea is located amidst the great deserts of Central Asia (Figure 1). A terminal lake, it has surface inflow but no surface outflow. Therefore, the balance between inflows from two rivers, the Amu Darya and Syr Darya, and net evaporation (evaporation from its surface minus precipitation on it) fundamentally determine its level. In the recent geologic past (last 10,000–15,000 years), the sea has endured significant level fluctuations, perhaps as much as 40 m (Micklin, 2004, 2007). The major level changes prior to 1960 resulted from diversion of the Amu Darya westward so that it flowed into the Sarykamysh hollow, and sometimes farther through the Uzboy channel to the Caspian Sea after it overtopped Sarykamysh, rather than the Aral Sea. These diversions resulted from natural events (sedimentation of the bed and

Figure 1. The Aral Sea basin.

Subsequent breaching of the rivers left bank during spring floods) and from purposeful human actions (destruction of dikes and levees, built to keep the river flowing to the Aral, during times of conflict).

However, from the mid-18th century until the 1960s, sea level changes were less than 4.5 m (Bortnik, 1996). For the period of instrumental observation (1911–1960), the sea was unusually stable, with annual inflow and net evaporation never far apart (the average of each of these water balance components was around 55 km^3 for the period) (Bortnik and Chistyaevaya, 1990, p. 36; Micklin, 1994). Hence, the water balance was in long-term equilibrium with a maximum lake level variation of less than one meter.

The Aral Sea's drainage basin encompasses 1.8 million km^2 falling within seven nations: Uzbekistan, Turkmenistan, Kazakhstan, Afghanistan, Tajikistan, and Iran. However, only Kazahstan and Uzbekistan are riparian on the Sea, with each possessing an approximately equal length of shoreline. The entire Aral coastline within Uzbekistan lies within that nation's Karakalpakstan Republic.

At slightly more than 67,000 km^2, the Aral Sea, according to area, was the world's fourth largest inland water body in 1960, and, according to recent evidence, perhaps third after the Caspian Sea and Lake Superior (Micklin, 1991, pp. 42–54). As a brackish lake with salinity averaging near 10 g/L, less than a third of the ocean, it was inhabited chiefly by fresh water fish species. The sea supported a major fishery and functioned as a key regional transportation route. The extensive deltas of the Syr Darya and Amu Darya sustained a diversity of flora and fauna. They also supported irrigated agriculture, animal husbandry, hunting and trapping, fishing, and harvesting of reeds, which served as fodder for livestock as well as building materials.

Over the past four and one-half decades, the sea has steadily shrunk and salinized (Figure 2, Table 1). The main cause has been expanding irrigation that diminished discharge from the two tributary rivers to a fraction of earlier volumes. The Aral separated into two water bodies in 1987–1989 – a "Small" Sea in the north and a "Large" Sea" in the south. The Syr Darya flows into the former, and the Amu Darya into the latter. Between 1960 and 2007, the level of the Small Aral fell by more than 11 m and the Large Aral by 24 m. Over this same period, the area of both seas taken together diminished by over 80% and the volume by more than 90%. By 2007, the Large Aral Sea had separated into four distinct water bodies: a "deep" western lake and a "shallow" eastern lake with a long, deep, narrow, channel connecting them, Tshche-Bas Bay, now cut-off most of the year from the Eastern Large Aral, and a chain of very shallow, ephemeral lakes leading from the Small Aral overflow channel to the Eastern Large Aral.

Since the late 1980s, a channel (river) has intermittently connected the Small and Large seas, with the flow from the former to the latter. In the early 1990s, local Kazakhstani officials constructed an earthen dike to block the flow from the Large to Small seas and raise the level and improve the fishery and ecology of the latter. However, the dike breached, necessitating

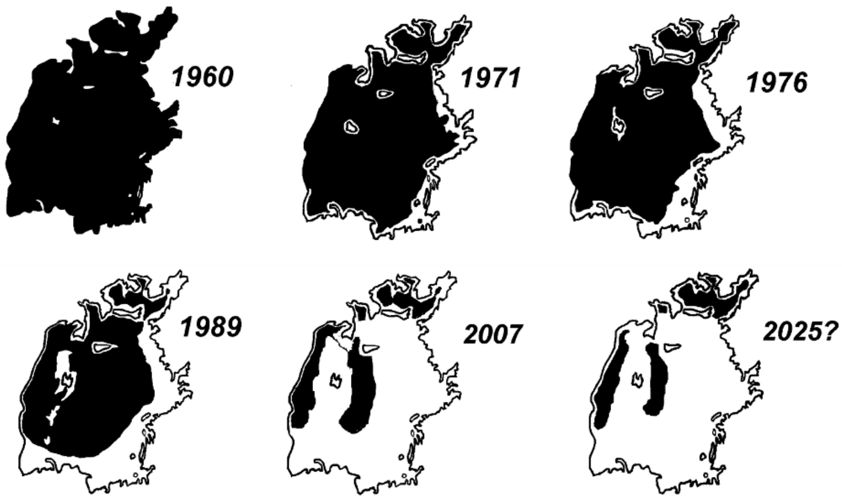


Figure 2. The changing profile of the Aral Sea.

TABLE 1. Hydrological and salinity characteristics of the Aral Sea, 1960–2025.

Year (part of Aral Sea)	Level (m asl)	Area (km^2)	% 1960 area	Volume (km^3)	% 1960 volume	Avg. salinity (g/L)	% 1960 salinity
1960 (Whole)	53.4	67,499	100	1,089	100	10	100
Large	53.4	61,381	100	1,007	100	10	100
Small	53.4	6,118	100	82	100	10	100
1971 (Whole)	51.1	60,200	89	925	85	12	120
1976 (Whole)	48.3	55,700	83	763	70	14	140
1989 (Whole)		39,734	59	364	33		
Large	39.1	36,930	60	341	34	30	300
Small	40.2	2,804	46	23	28	30	300
2007 (Whole)		13,958	21	102	9		
Large	29.4	10,700	17	75	8	East >100	>1,000
						West 100	100
Small	42.0	3,258	53	27	33	10	10
2025 (Whole)		9,658	14	68	6		
Large[a]	21–28.3	6,400	10	41	4	>200	>2,000
Small	42.0	3,258	53	27	33	<10	<100

[a]The sea will consist of a western and eastern part with the west basin at 21 m width and the east at 28.3.

Sources: Compiled from Asarin and Bortnik, 1987 and Bortnik and Chistyaevaya, 1990, Table 8.4, p. 72; Glavgidromet, 1994–2003; Water Balance, 1990–2006; Final Report, 2004; Ptichnikov, 2000, 2002; and Expedition, 2005, 2007.

rebuilding several times. A catastrophic dike failure in 1999 totally destroyed the dike and killed two people (Expedition, 2005, 2007). Following this event, the World Bank and Kazakhstani Government signed an agreement to construct an engineeringly sound structure. The new dike project was completed in August 2005 at a cost of US$85 million (Expedition, 2005). By early 2006, well ahead of schedule, the 13-km dike had raised the sea two meters to the design level of 42 m above the World Ocean, freshening the water body and improving its ecological condition as well as fishery prospects. Flow from the Syr Darya in excess of that needed to maintain the design level is released through an array of discharge gates and flows southward to the Large Aral Sea.

2.2. ENVIRONMENTAL AND HUMAN PROBLEMS OF ARAL SEA DESICCATION

The mainly human-induced desiccation of the Aral Sea and flow reduction, salinization, and pollution of its influent rivers has had severe negative impacts (Micklin, 2000, pp. 13–23; Micklin, 2004, 2007). Besides the consequences for the sea proper, a zone around the water body of several hundred thousand square kilometers with a population of several million has also been damaged. (Khvorog, 1992). The Republic of Karakalpakstan in Uzbekistan and portions of Kzyl-Orda Oblast in Kazakhstan, have suffered the most harm. Turkmenistan, although not abutting on the sea, has one Oblast, Dashauz, that has been substantially impacted.

The substantial Aral fishing industry developed by Kazakhstan and Uzbekistan in the first half of the 20th century ended in the early 1980s as indigenous fish disappeared from the effects of rising salinity and loss of shallow spawning and feeding areas (Micklin, 1991, pp. 49–50; Micklin, 2000; p. 16; Micklin, 2004, 2007; Williams and Aladin, 1991; Zholdasova et al., 1998; Ptichnikov, 2002). Due to the loss of the fishery and its affiliated industries, tens-of-thousands were thrown out of work. Navigation on the Aral also ceased by the 1980s as efforts to keep the increasingly long channels open to the major ports of Aral'sk at the northern end of the sea in Kazakhstan and Muynak at the southern end in Karakalpakstan became too difficult and costly. Fortunately, the deltaic lakes and Amu Darya and Syr Darya rivers have provided refuge for indigenous species. Also, the introduced Black Sea flounder (Kambala) flourished in the Small Aral and has provided a sizable catch for local fishers (Expedition, 2005). The project raising the level of the Small Aral Sea has lowered salinity sufficiently that indigenous species with commercial value such as the Sudak (Pike-perch), Sazan and Lyosh (types of carp), and Plotva (Roach) are making a strong come back, greatly improving the fishery potential of this water body (Expedition, 2007).

The rich ecosystems of the extensive Amu Darya delta, primarily located in the Karakalpak Republic of Uzbekistan but stretching into Turkmenistan have suffered considerable harm (Micklin, 1991, pp. 50–52; Micklin, 2004, 2007). Lesser, but substantial damage, has also accrued to the Syr Darya delta in Kazakhstan. Greatly reduced river flows through the deltas, the virtual elimination of spring floods in them (owing both to reduced river flow and construction of upstream storage reservoirs) and declining ground water levels, caused by the falling level of the Aral Sea, have led to spreading and intensifying desertification. Halophytes, plants tolerant of saline soils, and xerophytes, plants tolerant of dry conditions, are rapidly replacing endemic vegetation communities (Novikova, 1996, 1997). In some places, salts have accumulated on the surface forming solonchak (salt pans) where practically nothing will grow. Expanses of unique tugay (vegetation communities of trees, bushes, and tall grasses, including popular, willow, oleaster, salt cedar, and reeds) that formerly stretched along all the main rivers and distributary channels here have been particularly hard hit. According to Dr. Novikova (1996) whereas Tugay covered 100,000 ha in the Amu Darya delta in 1950, it shrank to 52,000 ha by the 1970s and to only 15,000–20,000 ha by the mid-1990s. Tugay complexes around the Aral Sea are habitats for a diversity of animals, including 60 species of mammals, more than 300 types of birds and 20 varieties of amphibians.

Delta desiccation significantly diminished the area of lakes, wetlands, and their associated reed communities. Between 1960 and 1980, the area of lakes in the Amu Darya delta is estimated to have decreased from 49,000 to 8,000 km^2 whereas the area of reeds may have diminished from 500,000 ha to as little as 1,000 ha from 1965–1986 (Chub, 2002, Figure 3.3, p. 125; Palvaniyazov, 1989). Serious ecological consequences have resulted as these areas provide prime habitat for a variety of permanent and migratory waterfowl, a number of which are endangered (Micklin, 1991, p. 116). Diminution of the aggregate water surface area coupled with increasing pollution of the remaining water bodies (primarily from irrigation runoff containing salts, fertilizers, pesticides, herbicides, and cotton defoliants) has decimated aquatic bird populations. However, in the late 1980s and in the 1990s, significant efforts were made to restore wetlands, improve habitat conditions, and reduce pollution (Chub, 2002, p. 125). A 1999 survey, for example, indicated that the area of reeds for the key lake/wetland in the lower delta, Sudochye, had expanded to 12,000 ha. (Dukhovnyy, 2003).

Irrigated agriculture in the deltas of the Amu Darya and Syr Darya suffers from an inadequacy of water as inflow to the deltas has decreased owing to heavy upstream consumptive use for irrigation. Additionally, water that does reach the deltas has elevated salinity from the leaching of salts caused by repeated usage in the middle and upper courses of the rivers (World Bank, 1998, pp. 3–5). At times over 2 g/L/, these saline flows have lowered crop yields and, in conjunction with inadequate drainage of irrigated fields, promoted secondary soil salinization. Animal husbandry, both in the deltas and desert regions adjacent to the Aral Sea, has been damaged by reduction of the area and declining productivity of pastures resulting from desertification, dropping groundwater levels, and replacement of natural vegetation suitable for grazing by inedible species.

Frequent strong winds blow sand, salt and dust from the dried bottom of the Aral Sea, largely a barren desert, onto adjacent lands. Satellite images have revealed major salt/dust plumes extending 200 to more than 500 km downwind that drop dust and salt over a considerable area adjacent to the sea in Uzbekistan, Kazakhstan, and to a lesser degree, in Turkmenistan (Micklin, 1991, pp. 48–49; Micklin, 2004; Glazovskiy, 1990, pp. 20–23; Ptichnikov, 2002). Although dust/salt storms affect the entire zone surrounding the Aral, most of the major storms occur with north and northeast winds, which most seriously impact the Ust-Urt Plateau to the sea's west and the Amu Darya delta at the south end of the water body (Bortnik and Chistyaevaya, 1990, p. 27, Figure 2.7). The latter is the most densely settled as well as economically and ecologically important region around the sea. N. Glazovskiy (1990, pp. 21–22) reviewed the various estimates of the total deflated material, ranging from 13 million to as high as 231 million metric tons/year, which were made in the 1980s. He concluded that the most probable figure was from 40 to 150 million tons.

Salts in dry and aerosol forms, the most harmful of which include sodium bicarbonate, sodium chloride, and sodium sulfate, are settling on natural vegetation and crops, particularly in the Amu Darya delta (Bel'gibayev, 1984). In some cases, plants are killed outright but more commonly their growth (and for crops, yields) is substantially reduced. The salt and dust also has ill effects on wild and domestic animals by directly harming them and by reducing their food supply (Palvaniyazov, 1989). Local health experts also consider airborne salt and dust as a factor contributing to high levels of respiratory illnesses and impairments, eye problems, and possibly even throat and esophageal cancer in the near Aral region (Abdirov et al., 1993; Tursunov, 1989). More recent field work by a British led group indicates that salt and dust blowing from the dried bottom (and likely from irrigated farmland in regions adjacent to the Aral Sea) is laced with pesticides and heavy metals, which, of course would enhance the negative impacts on humans and other animals (O'Hara et al., 2000).

Owing to the sea's shrinkage, climate has changed in a band up to 100 km wide along the former shoreline in Kazakhstan and Uzbekistan (Micklin, 1991, pp. 52–53; Glazovskiy, 1990, pp. 19–21). Maritime conditions have been replaced by more continental and deseritic regimes. Summers have warmed and winters cooled, spring frosts are later and fall frosts earlier, humidity is lower, and the growing season shorter. Uzbekistani climatological experts also believe that the increase in the levels of salt and dust in the atmosphere are reducing levels of surface radiation and thereby photosynthetic activity as will as increasing the acidity of precipitation (Chub, 2002).

The population living in the "ecological disaster zone" suffers acute health problems (Micklin, 1992; Medecins Sans Frontieres, 2000). Some of these are direct consequences of the sea's recession (e.g., respiratory and digestive afflictions and possibly cancer from inhalation and ingestion of blowing salt and dust and poorer diets from the loss of Aral fish as a major food source). Other serious health related problems owe to environmental pollution associated with the heavy use of toxic agricultural chemicals (e.g., pesticides and defoliants for cotton). This usage was primarily during the Soviet period and has been greatly reduced since the disintegration of that nation in 1990.

However, the most serious health issues are directly related to 'Third World' medical, health, nutrition and hygienic conditions and practices. Bacterial contamination of drinking water is pervasive and has led to very high rates of typhoid, paratyphoid, viral hepatitis, and dysentery. Owing primarily to efforts of the international donor community, the quality and safety of drinking water has seen major improvement since the mid 1990s.

Tuberculosis is prevalent as is anemia, particularly in pregnant woman. Liver and kidney ailments are widespread; the latter is probably closely related to the excessively high salt content of much of the drinking water. Medical care is very poor, diets lack variety, and adequate sewage systems are rare.

Health conditions in the Karakalpak Republic in Uzbekistan are possibly the worst in the Aral Sea Basin. Surveys conducted in the mid to late 1980s showed the average infant mortality rate at more than 70/1,000 live births whereas several districts adjacent to the former seashore ranged from 80 to over 100/1,000 live births (Micklin, 1992). These rates are three to four times the national level in the former USSR and 7–10 times that of the U.S. Although efforts have been made in the post-Soviet period to improve health conditions here, it is doubtful these rates have declined in any substantial way.

Perhaps the most ironic and dark consequence of the Aral's shrinkage is the story of Vozrozhdeniya (Resurrection) Island. The Soviet military in the early 1950s selected this, at the time tiny, isolated island in the middle of the Aral Sea, as the primary testing ground for its super-secret biological weapons program (Bozheyeva et al., 1999; Wijinsima, 2000). From then until 1990, they tested various genetically modified and "weaponized" pathogens, including anthrax, plague, typhus, smallpox and other disease causing organisms. These programs stopped with the collapse of the USSR in 1991. Allegedly the departing Soviet military took measures to decontaminate the island. As the sea shrunk and shallowed since the 1960s, Vozrozhdenia grew in size and in 2001 united with the mainland to the south as a huge peninsula extending into the Aral Sea. The fear has been that some weaponized organisms survived and could escape to the mainland via infected rodents or that terrorists might gain access to them. In the early part of the new millennium, the U.S. contributed $6,000,000 and sent a team of experts to the former island to help the Government of Uzbekistan ensure the destruction of any surviving weaponized pathogens ("Bioweapons' Cleanup," 2002).

3. Satellite remote sensing of the Aral

3.1. EARLY SATELLITE PHOTOGRAPHY OF THE ARAL

Satellite reconnaissance of the Aral dates from the late 1950s. The Corona, Argon, and Lanyard satellites (so-called "KH" series) were U.S. photographic surveillance satellites in service from 1959–1972 (http://msl.jpl.nasa.gov/Programs/corona.html). The satellites were designed to assess how rapidly the Soviet Union was producing long-range bombers and ballistic missiles, and where they were being deployed. The program's worldwide photographic coverage was also used to produce maps and charts for the Department of Defense and other U.S. government mapping programs. The satellites used film canisters that were returned to earth in capsules (a.k.a. "buckets") for evaluation. These capsules were designed to be recovered by a specially equipped aircraft during parachute descent, but were also designed to float to permit recovery from the ocean. All film was black-and-white, with the exception of some small samples of infrared and color film carried on some missions as experiments.

A large number of photos of the Aral Sea, ranging from high to low resolution, were taken under this program, but were classified until 1995, when they were released to the public and made accessible over the Internet. Figure 3 is an example of one of the low-resolution photos. It provides a

Figure 3. Argon Spy Satellite photo of Aral Sea, 8-21-64.

useful overall view of the Aral before the major modern recession took hold. Probably the main reason for interest in the Aral was the presence of the super-secret bioweapons complex on Vozrozhdeniye Island, discussed above.

3.2. THE MODERN ERA: LAND RESOURCE AND ENVIRONMENTAL SATELLITES

The launch of Landsat 1 in July 1972 inaugurated an era of the use of satellite imaging sensors to collect information on the terrestrial environment of the earth (http://www.landsat.org/). Over the past 36 years, Landsat 1 and its successors (Landsats 4–7) have collected a huge number of images over all parts of the land surface, including the Aral Sea and its environs. Other satellites and sensors with similar capabilities were launched in subsequent years. Of these, the French Spot system, in operation since 1986, the AVHRR (Advanced Very High Resolution Radiometer) on the U.S. polar orbiting meteorological satellites since 1978, the Soviet/Russian Resource satellite with the MSU-SK sensor launched in 1980, and the MODIS (Moderate Resolution Imaging Spectrometer) on the Terra and Aqua satellites (operational since February 2000) have been most important (Campbell, 1987, pp. 149–154, 390–393; http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html; http://disc.gsfc.nasa.gov/MODIS/.

These instruments collect emitted radiation in multiple spectral bandwidths (visible and near, mid, and thermal infrared) with resolutions ranging from 10–15 m (Landsat ETM and Spot) to 1.1 km for the AVHRR and MODIS. Repetitive coverage varies from twice daily for the AVHRR, MODIS and Resource to every 14–16 days for Landsat. The spectral channels the satellite sensors employ are intended to detect key aspects of the surface environment such as vegetation types and characteristics, land/water boundaries, turbid water, clear water, temperature, moisture content of soils etc. Data are collected in digital form and transferred to ground stations where they are converted to standard formats readable by a variety of commercial image processing/analysis and GIS software (e.g., IDRISI, ERDAS, ER Mapper). These powerful programs are used to turn raw image files into maps, GIS data layers, and other products to better understand, protect, and manage the environment around us.

I am most familiar with the use of Landsat, AVHRR, Resource, and MODIS imagery to study the Aral Sea and its adjacent region. In 1987, I worked with EOSAT (The Earth Observation Satellite Company), which for a period managed the operation of the Landsat satellites, to use Landsat imagery to determine the changing area of the Aral Sea. The approach was relatively simple. They provided 1977 and 1987 physical mosaics of the sea consisting of 11 scenes each, and I used a polar planimeter to measure the area of key features (Figure 4; Table 2). The exercise quantitatively demonstrated the rapid shrinkage of the sea over this decade and the utility of even simple analysis of Landsat images for this purpose.

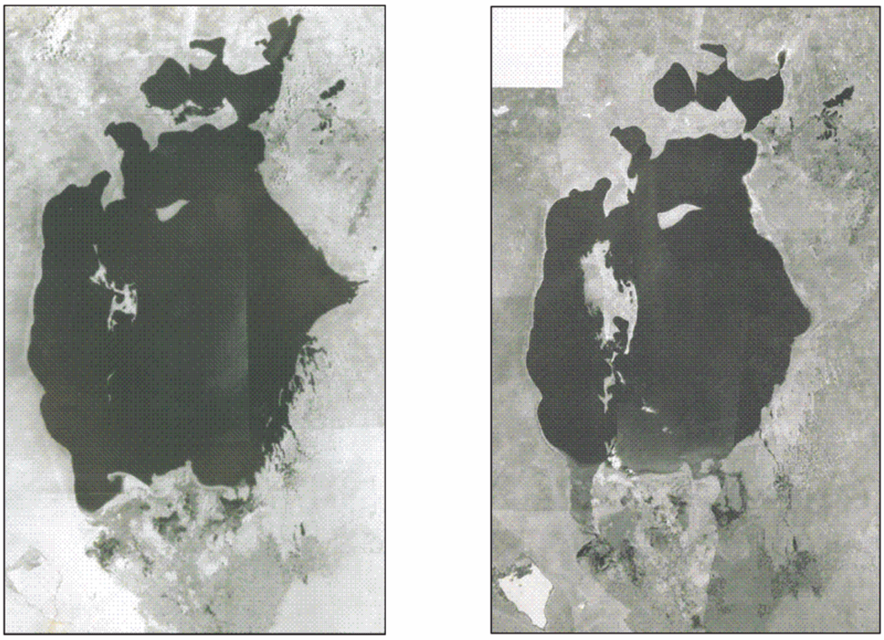


Figure 4. Landsat MSS image mosaics of the Aral Sea.

TABLE 2. Area changes of Aral Sea 1977–1987 determined from Landsat MSS Imagery.

Physical feature	Area in 1977 (km^2)	Area in 1987 (km^2)	Change 1977–1987 (km^2)	% change 1977–1987
Aral sea (including islands)	53,950	44,010	-9,940	-18.4
1.Small Sea	4,486	2,886	-1,600	-35.7
2. Large Sea	49,464	41,123	-8,340	-16.9
Islands	616	2,363	1,748	283.8
1. Barsa Kel'mes	203	306	103	50.6
2. Vozrozhdeniya	413	1,786	1,373	332.8
3. Other		272	272	
Aral Sea (without islands)	53,344	41,646	-11,688	-21.9

In the early 1990s, I used digital Landsat MSS (Multi-Spectral Scanner) and AVHRR images to study the land cover of the Amu Darya delta. For both, IDRISI image analysis/GIS software, developed atClark University, was employed to produce composite three-band images, which were then used to produce unsupervised landscape classifications. The software delineates the classes according to spectral homogeneity and the analyst interprets what they represent. Figure 5a and b below show classified Landsat

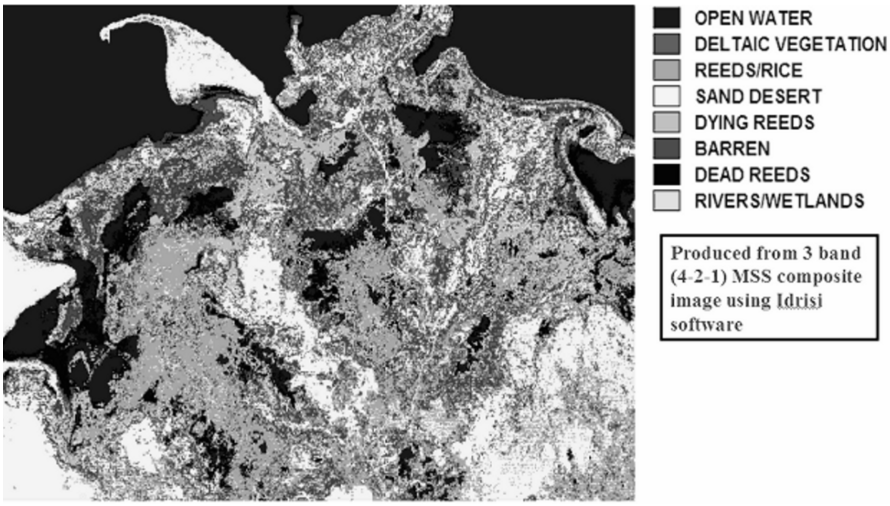


Figure 5a. Unsupervised classification of lower Amu Darya delta (September 14, 1973).

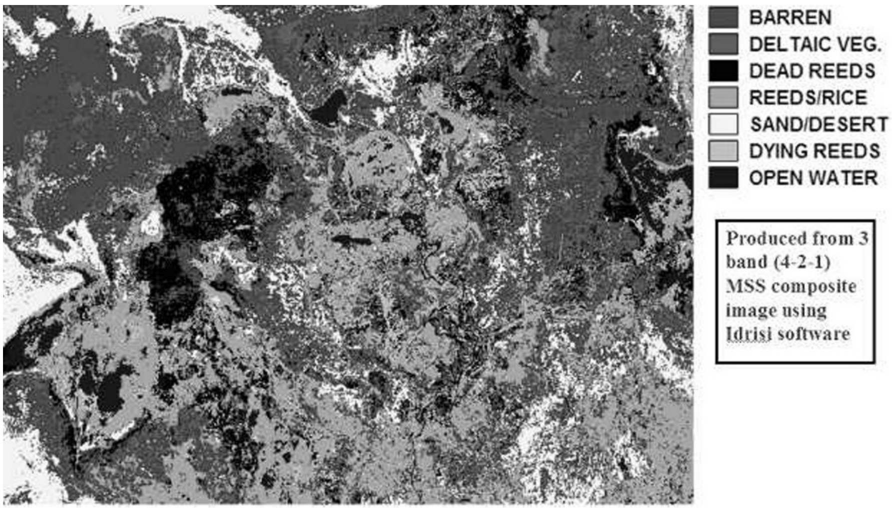


Figure 5b. Unsupervised classification of lower Amu Darya delta (August 16, 1989).

images from 1973 and 1989 for the lower Amu Darya Delta and Table 3 shows the area of different land classes for the two dates and the changes that have occurred. The effects of the rapid and relentless desiccation of the Aral Sea and the adjacent parts of the Amu Darya Delta over the 16 years are pronounced and dramatic. Table 4 below shows the results of an unsupervised classification of a composite AVHRR image of the land cover for the entire Amu Darya delta.

From 1994–2003, I was a member of a group involved in a series of projects funded by the NATO Science Programs (http://www.nato.int/science/) to develop the capacity of the Republic of Karakalpakstan, part of Uzbekistan, to gather environmental data and provide analysis of those data to help support decision-making that was both environmentally sustainable and economically viable. Others who played a major role in this work were Dr. Andrey Ptichnikov, Institute of Geography, Russian Academy of Sciences, Dr. Rainer Ressl, German Space Agency, Dr. Nina Novikova, Institute of

TABLE 3. Landscape categories for lower Amu Darya delta from Landsat Imagery.

Landscape category	Area in 1973 (km^2)	Area in 1989 (km^2)	Percent change 1973–1989
Open water	4,060	927	-77.2
Sand/desert	3,519	2,287	-35.0
Deltaic vegetation	2,999	4,091	36.4
Reeds (alive)	2,878	4,066	41.3
Reeds (dying)	1,817	957	47.3
Barren land	1,454	4,840	232.9
Dead reeds	1,138	1,493	31.2
Rivers/wetlands	796	0	
Total	18,661	18,661	

TABLE 4. Unsupervised classification of the Amu Darya delta for August 14, 1986 from AVHRR Imagery[a].

Landscape category	Area (km^2)	% of area
1. Desert soil	79,122	59.89
2. Delta vegetation and irrigated crops	19,273	14.59
3. Salinized soil	14,581	11.04
4. Alluvial soil	13,183	9.98
5. Deeper water	1,249	0.95
6. Shallow water	1,056	0.80
7. Wet solonchak soil	1,186	0.90
8. Dry solonchak soil	937	0.71
9. Turbid water	671	0.51
10. Wetlands	863	0.65
Total	132,121	100.00

[a]Classification of composite image, bands 2,1,4, using IDRISI software.

Water Problems, Russian Academy of Sciences and Dr. Polat Reimov, Chair of the Geography Dept., Karakalpakstan State University. In addition, at one time or another, 23 other researchers were involved in these efforts. The projects were housed in the Geography Dept. of Karakalpakstan University, which served as a training, data gathering, and analysis center. The center also provided outreach, training, and collaborative support to a number of government entities in Karakalpakstan (including water, agricultural, environmental, statistical and landuse planning agencies) as well as to national and interstate agencies concerned with water resources management, hydrology and meteorology in Tashkent, the capital of Uzbekistan. The center also provided aid and advice to a number of environmental NGOs in Karakalpakstan.

Landsat, AVHRR, Resource, and MODIS satellite imagery played a crucial part in this work. There is not room to cover all facets of this complex effort related to digital satellite imagery, but brief description of some of the products our project generated that are useful in studying and monitoring environmental change in the Aral Sea region is useful. Dr. Ptichnikov used a 1989 Landsat TM (thematic mapper) image to elucidate the degree of "desertification" (i.e., the dynamic process where, under the force of increasing aridity and soil salinity, drought and salt tolerant plant communities replace endemic vegetation associations requiring more moist environments) in the lower Amu Darya delta (Ptichnikov, 2000). This process is the most pernicious of the trends occurring here. Clear understanding of its spatial extent and dynamics is essential to developing ameliorative strategies.

Dr. Novikova, an expert geobotanist from the Institute of Water Problems in Moscow and Dr. Ptichnikov (assisted by a graduate student) produced a detailed landscape map (Figure 6) of the Amu Darya Delta for our NATO project (Ptichnikov, 2002–2003). Two Landsat ETM (enhanced thematic mapper) images from July and August 2000 were used in the work. Below is a somewhat rewritten (for better understanding) excerpt from our final project report to the NATO Science Program about the process and its significance (Final Report, 2004, pp. 27–30).

The considerable change of the landscape structure of the southern Aral Region caused by desertification compared with the beginning of the 1990's, when the last landscape map was made, requires a new map, which more precisely reflects the state of the environment. We created the landscape map of 2000 by updating the existing GIS landscape map of 1980. The main sources of new information were gained through interpretation of two Landsat 7 ETM images for the Amu Darya delta and the dried sea bottom (23 August 2000). Data from ground exploration, using a GPS for exact location, that included determining depths and salt contents of ground waters

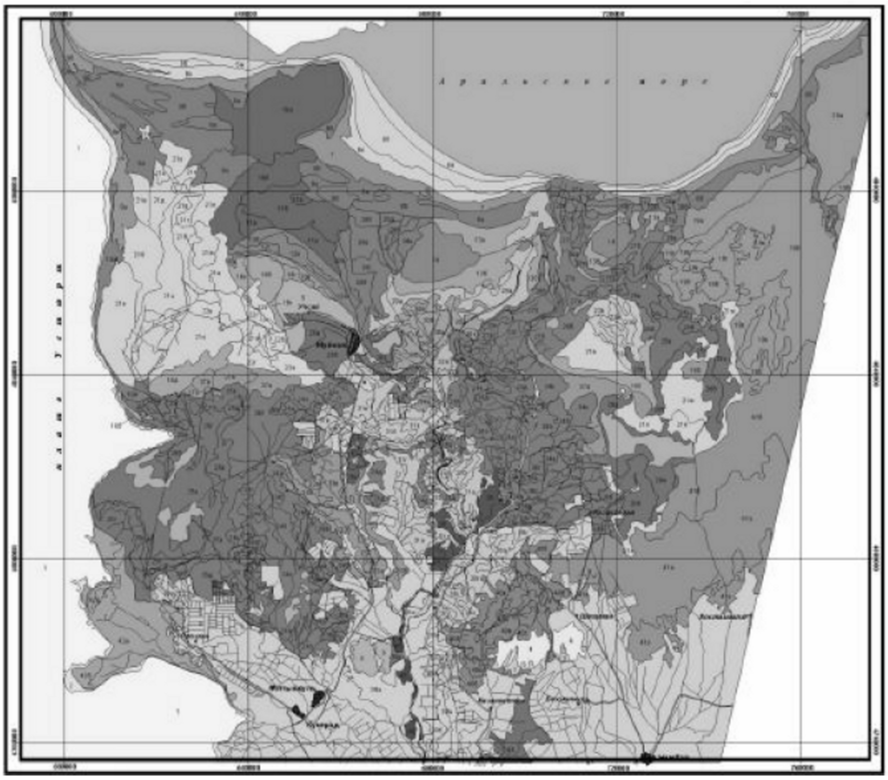


Figure 6. Ecosystem (landscape) map of the lower Amu Darya delta and the dry bottom of the Aral Sea.

as well as studying vegetation and exogenous processes, were used as well. The map of 2000 contains new information for the sea bottom, which had dried since 1980, and became subject to the dynamics of the revegetation process. As the landscape map is synthetic, bringing together complex information about natural landscapes, it consists of several layers, i.e. geostructures, geomorphological and genetic complexes, hydrographical network, ground water, soil, vegetation and landscape classes. The legend of the landscape map is presented below. It includes 41 landscape subtypes in 11 classes. The landscape map is generated in GIS and can be easily updated and used for monitoring purposes. It is the most precise landscape map of the southern Aral.

Dr. Rainer Ressl has done some of the most useful remote sensing/GIS work on the Aral Sea. Formerly affiliated with the German Space Agency and the German Center for Remote Sensing, he now is director of GIS and remote sensing for CONABIO (the Mexican Federal Agency for the Conservation, Knowledge and Distribution of Information on Biomes and Biodiversity). He was a key member of our NATO research group from

1994–2003. Among his main contributions were the use of satellite image and GIS analysis methods to study and document the shrinkage of the Aral Sea and to study land use in the Amu Darya delta as a means to develop a crop optimization model as a decision support guide to improving land and water use and agriculture here.

For studying the shrinkage of the Aral Sea from 1985–2002, he used digital imagery from the AVHRR sensor on the American Polar orbiting satellites at a resolution of 1.1 km, from the MSU-SK sensor on the Russian Resource satellite (resolution of 170 m), and from the MODIS sensor on the American Terra satellite (resolution 250 m) (Ressl, 1996; Ressl and Micklin, 2004). Dr. Ressl utilized a sophisticated image analysis technique based on the differing spectral properties of land and water to create "land-water masks" for each year. He then employed a software algorithm that counted the water pixels and multiplied these by the area of each pixel to get a water area for each year (Table 5). A bathymetric model of the sea digitized from the 1:500,000 Soviet bathymetric map was then used in association with a physical water balance model developed by Philip Micklin to estimate levels, areas, and volumes for the sea from 2003 to 2010. The information gained via this effort is of crucial importance not only to understand what has happened to the sea, but also to develop reasonable scenarios as to what the future may bring and how to cope with likely changes.

TABLE 5. Aral Sea area as derived from Satellite Imagery and a Water Balance Model[a,b].

Year	Sea level (m)	Area (km^2)
1960	53.0	69,384
1985	41.5	44,468
1986	40.5	43,278
1987	40.0	42,517
1988	39.5	41,470
1989	39.0	39,543
1990	38.0	38,163
1991	37.0	35,412
1992	36.5	33,635
1996	36.0	31,427
2000	32.9	22,500
2002	32.5	21,200
2003	31.9	19,427
2004	31.6	18,668
2005	31.4	17,980
2006	31.2	17,361
2007	31.0	16,810
2008	30.8	16,228
2009	30.7	15,732
2010	30.6	15,314

[a]Levels for 1990–2010 are for Large Sea only

[b]Sea level and area for 2003–2010 are estimates

Dr. Ressl used data from the MODIS sensor to study land use in the Amu Darya delta and to develop a crop optimization model for here. Below is an edited excerpt from our group's final report to the NATO Science Program that describes this work (Final Report, 2004, pp. 40–42).

Satellite remote sensing techniques are a crucial information source for improving irrigation water management in the Amu-Darja-Delta. The continuous monitoring of water demand of different land uses over the phenological [growing] cycle up to the point of harvesting serves as a basis for large-scale irrigation management. This task can be accomplished by using multitemporal high or medium spatial resolution remote sensing data. Especially noteworthy are the satellite data from the relatively new MODIS-Terra sensor, as data is provided free of charge to the user community, which is crucial for long-term applications and acceptance of this data type and this technology. With spatial resolutions of the 36 available spectral bands ranging from 250 m to 1000 m, the derived land use classifications are sufficient to get a crude estimation of current land use and associated water consumption. Crop phenology information can be used to calculate potential and actual evapotranspiration (PET, AET) of crops during their growing cycle. This information can be used to enhance irrigation measures by applying the correct amount of water on each agricultural plot based on the individual crop's growing cycle. Calculating the Normalized Difference Vegetation Index (NDVI) with multitemporal MODIS data can derive crop phenology information. MODIS data for the years 2001 and 2002 were evaluated to obtain crop specific growing curves, which were related to water consumption applying crop coefficients. More than 150 GPS reference points were collected in the Amu-Darja-Delta in summer 2002 to obtain the necessary representative classes. For the most important crop types the PET was calculated: rice 1415 mm, cotton 1190 mm, lucerne [alfalfa] 1178 mm, wheat 1048 mm, Others 920 mm. The growing cycle in the Amu-Darja delta for the period of June to September is illustrated in fig. 19 To obtain the potential water need for the entire delta a land use classification was derived using MODIS data for the year 2002. A supervised classification was developed using a maximum-likelihood classifier and the first 7 spectral bands. The 500m bands were resampled to a ground resolution of 250m for this purpose.

The results show that MODIS data are suitable for land use classifications for the main crop types in the Amu-Darya-delta. Due to the relatively coarse spatial resolution (250/500 m) the classification focused on the main crop types (rice and cotton), as these are cultivated on large plots (>250 m). The other land uses were grouped to "others". The classification errors due to the spectral similarity of different land use classes (e.g. rice and reeds) could be partially resolved by applying previous knowledge from the phenology (seasonal growth cycle) characteristics of the crops. Land use information on a yearly basis can be a source of valuable supplemental information for local decision makers and for local water management on a delta-wide scale. For water management on individual plots, nevertheless, satellite data with higher spatial resolution or on site information is necessary.

4. The future

The application of remote sensing and GIS techniques to the Aral Sea problem over the past four decades has been key to studying and monitoring the incredibly rapid and pronounced environmental change that has taken place. Through analysis of digital satellite imagery and the creation of useful GIS products we have a much clearer picture of what has occurred and what might occur, enhancing science-based support for optimal decision-making.

The future in regard to the use of these methods, and some new techniques, for studying the sea and its environs is bright. Let me mention some of the most interesting trends and developments. Easy access to satellite imagery via the Internet is a very exciting development of recent years. In my view, MODIS imagery from the Terra satellite, available since 2000, and Aqua satellite, available since 2002, is of the greatest use and value. Each satellite scans the earth twice daily in 36 bands with resolutions of 250 and 500 m as well as 1, 2, and 4 km. A series of "canned" composite three-band images in JPEG format of the Aral Sea region, with accompanying descriptions, may be found (use the search term "Aral Sea"), viewed and downloaded from NASA's MODIS "Rapid Response System" website by clicking on the Gallery button (http://rapidfire.sci.gsfc.nasa.gov/gallery/). A much larger number of MODIS images that include coverage of the Aral Sea may be found via the "Real Time" button at this website. Here imagery collected each day over the entire planet is accessible. The period of coverage is April 2001 to present. Because of the huge number of images, finding those that show the Aral Sea is a task. But orbital maps with accession times and monthly calendars are provided so, with some doggedness, I have been successful in locating and downloading (in JPEG format) a substantial number of images. The images are available in several three-band JPEG formats, including true color and NDVI (normalized difference vegetation index). I have found true color (a combination of bands 1,4,3) most useful for studying the Aral Sea and surroundings. It is also possible for some images to download the raw band data that is suitable for processing via standard remote sensing software. However, one must obtain from the website free software for downloading these data, which are in a type of hdf (high density format) that is not readable by many remote sensing analysis programs and converting this to Geotiff format, which is readable by all contemporary remote sensing software.

MODIS imagery owing to its frequency, resolution, and currency is excellently adapted to monitoring Aral Sea environmental conditions and their changes over time. Figure 7 shows four MODIS images of the entire sea from 2001 to 2007 and graphically traces the rapid shrinkage over this period of the Large Aral. Figure 8 shows the quite different contemporary flow conditions from the Small to Large Aral between Spring and Summer.

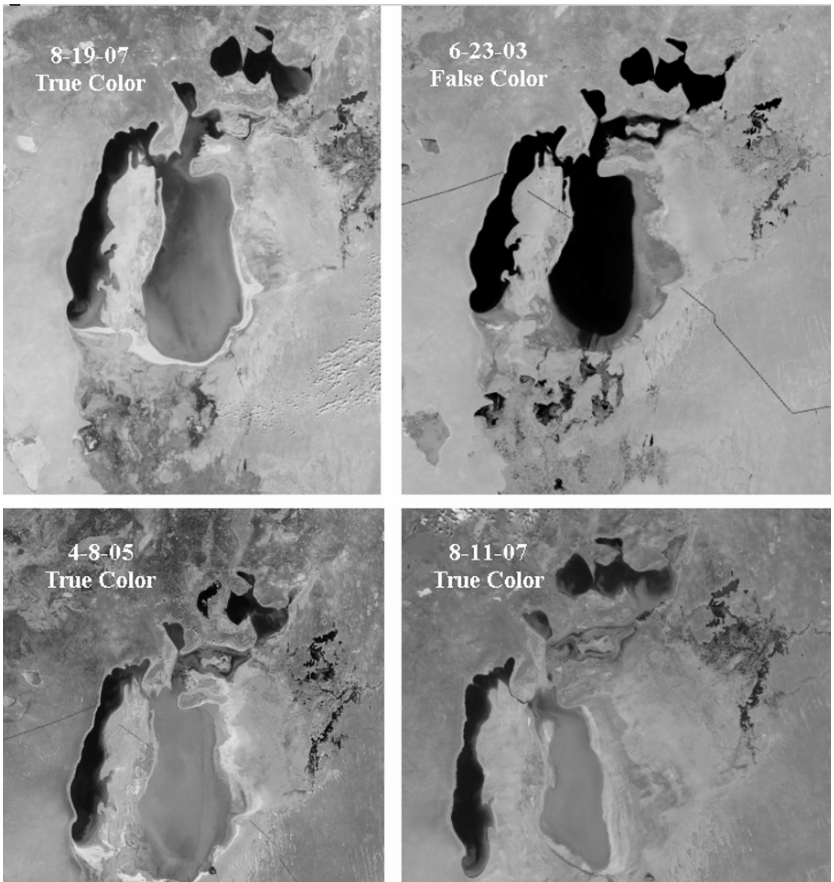


Figure 7. MODIS 250 m, images of the Aral Sea.

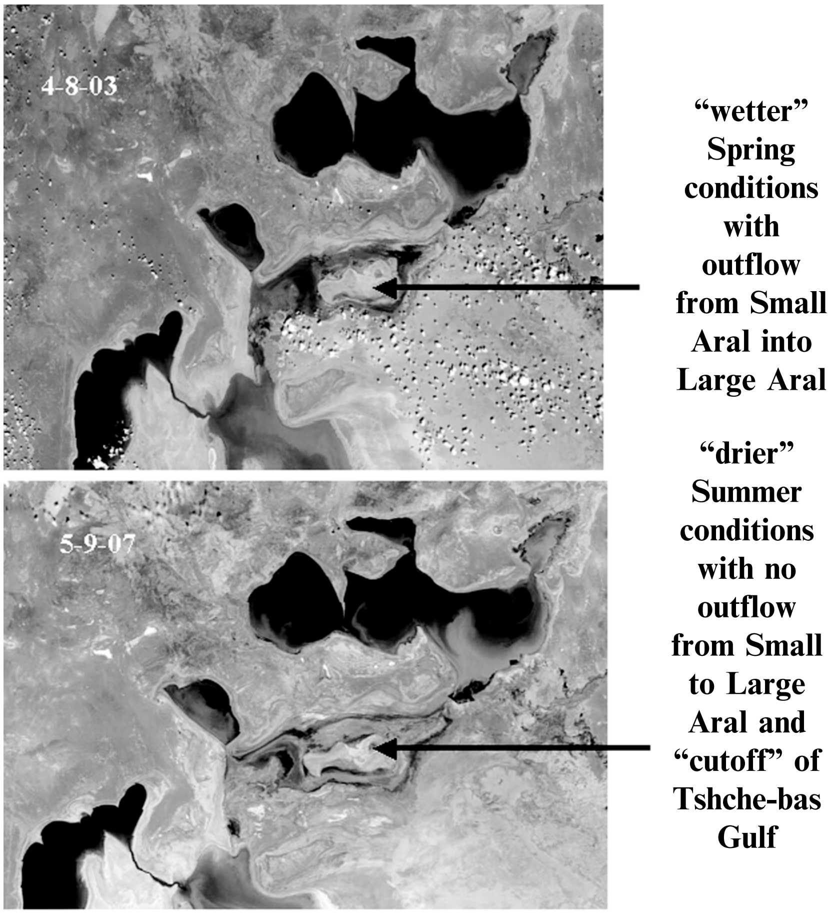


Figure 8. MODIS 250 m images of Spring and Summer flow conditions from small to large Aral Sea.

Figure 9 shows the large dust/salt storms that plague the Aral region. Figure 10 demonstrates the use of MODIS imagery in combination with the 1:500,000 Soviet era bathymetric map to estimate the level of the Large Aral Sea within about one-half meter.

The "ASTER" (Advanced Spaceborne Thermal Emission and Reflection Radiometer) sensor on the Terra and Aqua satellites could also prove useful for studying the Aral Sea and environs. It provides resolutions of 15 m in the visible and near infrared, 30 m in the short-wave or near infrared, and

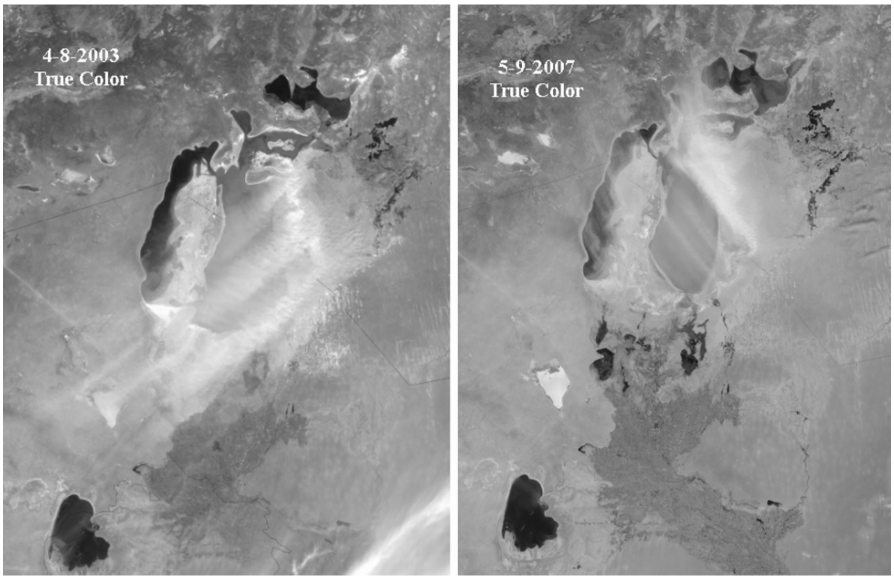


Figure 9. MODIS 250 m images of dust and salt storms.

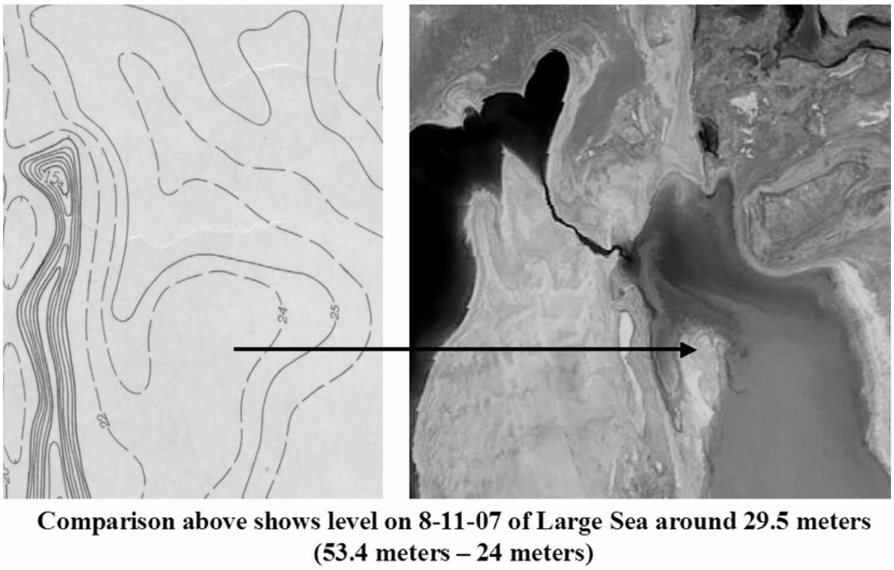


Figure 10. Using MODIS image (right) and bathymetric map (left) to estimate Aral Sea level.

90 m in the thermal infrared, thus providing much more detailed views than MODIS. Reduced resolution images of the Aral Sea and environs from ASTER (1 km, 400 m and 90 m) are viewable and downloadable in JPEG format at http://glovis.usgs.gov. However, the coverage is only for part of

2002. Two 90-m ASTER VNIR (visible and near infrared) images are shown in Figure 11. They show the Mezhdurechenskoye reservoir/wetland in the lower delta of the Amu Darya and the outflow from it to the Aral Sea in the second half of July 2002. If coverage were made more regular, this imagery would be very useful for monitoring flow into the Large Aral from the Amu Darya – a quantity that is essential to calculating the Aral's water balance, but is now, at best, just an educated guess.

There is also access to some Landsat imagery of the Aral Sea and vicinity via the web. Full Thematic Mapper scenes that can be manipulated via remote sensing/GIS software still cost $600 each (http://landsat.usgs.gov). Furthermore, the only Landsat now in orbit is Landsat 7 ETM+ (Enhanced Thematic Mapper), which since May 2003 has had scan problems resulting in images with diagonal black lines. There is a strong possibility Landsat 8 will be launched in 2010 (http://igic.gis.iastate.edu/member_folder/news/landsat-8). Older, reduced resolution composite imagery is viewable on the internet. The two best sites that I have seen are Google Earth (http://earth.google.com) and the USGS (United States Geological Survey) Global Visualization Viewer Web site (http://glovis.usgs.gov). The former has zoomable imagery for the whole earth. Hence, for the Aral you can go from a view of the whole sea (or whole region) down to fairly high-resolution views (that appear to be Landsat natural color from about 2000). [Note: much higher resolution images than Landsat are also available on Google Earth for a few locations around the Aral Aral Sea. I don't know the source

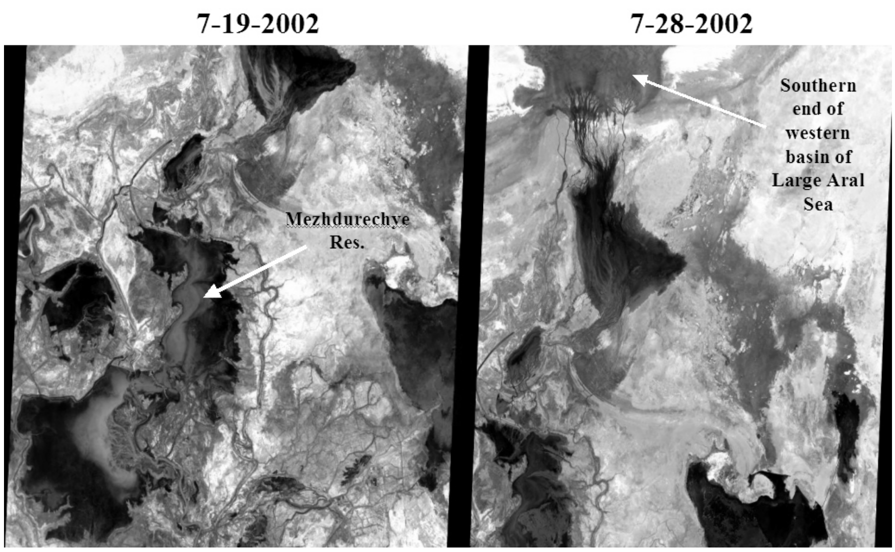


Figure 11. ASTER VNIR images of the Mezhdurechenskoye Reservoir (left) and outflow from it to the Aral Sea (right).

of these.] Figure 12 shows the whole Aral (left) and the Berg Strait area (right) before the dike was built, with flow going from the Small to Large Aral. The latter, on the other hand, has excellent Landat MSS and TM coverage of the Aral Sea at 1 km and 240 m from the 1970s to 2003. As far as I can tell, it is not possible to download (at least for free) images in JPEG format from either of these sources, but if you have a screen capture program (e.g. Corel Capture) you can “grab” whatever you can show on one screen. For example, using the USGS viewer, I found two very useful images just before and after the make-shift earthen dam blocking the flow from the Small to Large Aral breached and washed away in April 1999, releasing a huge quantity of water southward and killing two people (Figure 13).

Finally, another relatively recent technological development that shows great promise is the use of radar altimetry to deduce the level of the Aral Sea. The United States launched the first satellite with this capability (Topex/Poseidon) in 1992 (http://topex-www.jpl.nasa.gov/). A second satellite (Jason) was launched in 2002 as a joint U.S.-French project. Mainly used to measure ocean levels, a group headed by Jean-Francois Cretaux of the Laboratory for the Study of Geophysics and Ocean Topography (Laboratoire d’ Etudes en Geophysique et Oceanographie Spatiales [LEGOS]), has used the data gathered over the Aral Sea (once every 10 days) to formulate a monthly time-series of levels for the Small Sea and Large Sea from 1993–2006 (Cretaux et al., 2005, Cretaux and Birkett, 2006).

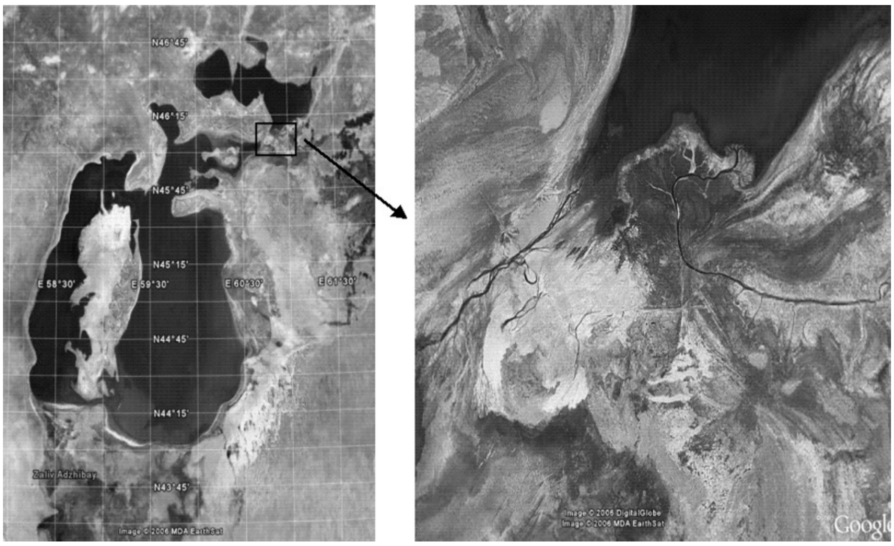


Figure 12. Google Earth images of the Aral Sea.

Figures 14 and 15 show these data. The accuracy is quite high with the standard deviation estimated at +6 cm. Given the difficulty of in situ level measurements of a water body experiencing rapid level changes and whose shoreline is inaccessible, these measurements are the most accurate available on any regular basis and are invaluable. They are and will continue to

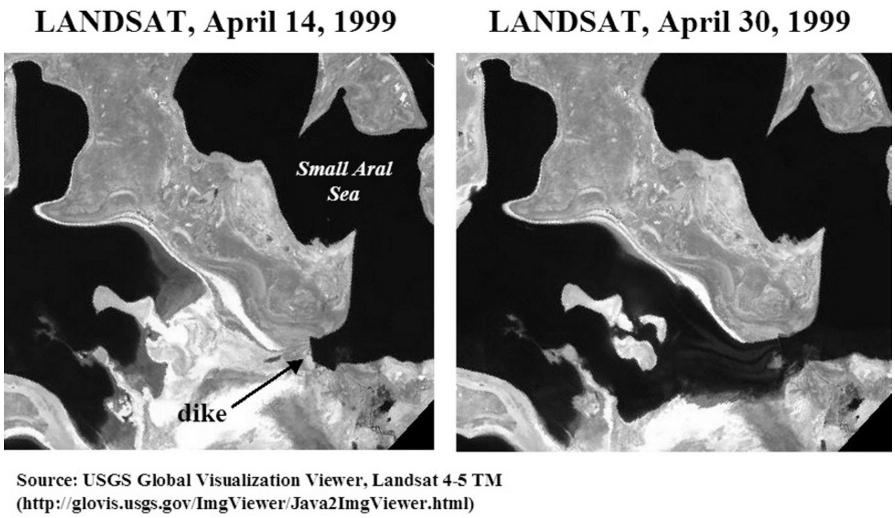
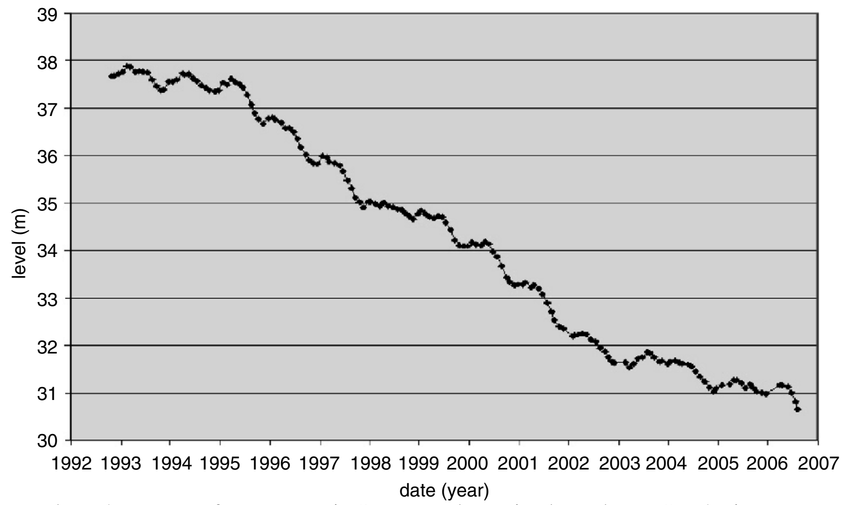
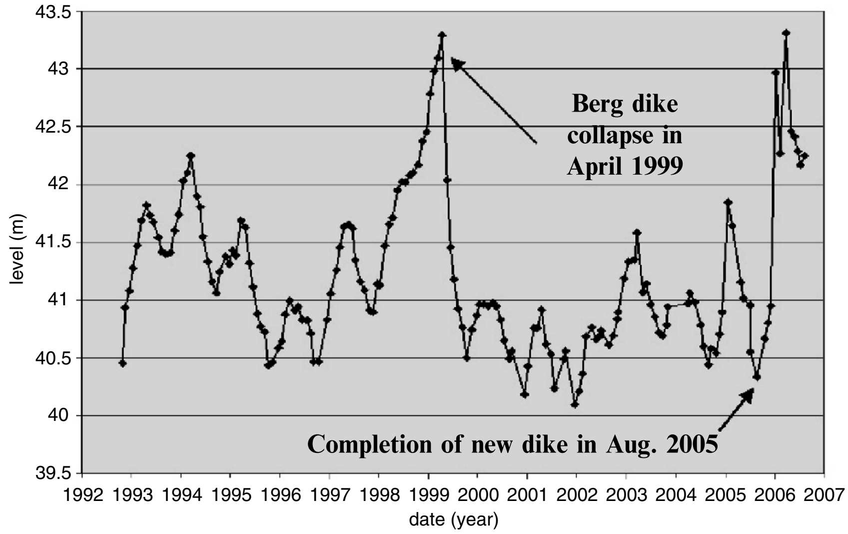


Figure 13. Berg Strait Dike before (left) and after (right) breaching (small Aral level fell nearly 3 m).



Excel graph courtesy of Jean-Francois Cretaux, Laboratoire d' Etudes en Geophysique et Oceanographie Spatiales, Toulouse, France

Figure 14. Large Aral Sea levels from Radar Altimetry.



Excel graph courtesy of Jean-Francois Cretaux, Laboratoire d' Etudes en Geophysique et Oceanographie Spatiales, Toulouse, France

Figure 15. Small Aral Sea levels from Radar Altimetry.

be crucial not only to tracking the level changes of the Small and Large Aral seas on a regular basis but to formulating more accurate models of the sea's water balance and more exact scenarios of its future state.

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MONITORING ARID LAND SURFACES WITH EARTH OBSERVATION TECHNIQUES: EXAMPLES OF INTENSE AND EXTENSIVE LAND USES

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Abstract. In using drylands ecosystems, human societies have adopted various strategies ranging from extensive nomadic pastures to intensive irrigated cash crop production. Monitoring the condition and performance of the various systems is essential to ensure their sustainability and to suggest and test adaptations to changing conditions (whether climatic or socio-economic). Earth observation techniques are providing unique datasets for monitoring the spatial and temporal dynamics of large areas. The challenges in using these data for assessing dryland condition are discussed here through two case studies. The first is a test site of Menzel Habib in southern Tunisia which has been subjected to a large number of research projects on ecology and rangeland degradation. Using a time series of Landsat images (MSS and TM) spanning more than 30 years, after registration and inter-calibration of the images, changes in land surface characteristics have been monitored. After an overview of techniques to detect and analyze changes, their interpretation in terms of ecological condition and desertification trend is discussed. In the second case, the irrigated agricultural plain of the Marrakesh region in southern Morocco has been subjected to intensive monitoring by high resolution satellites. A test area with large irrigated agricultural fields has been monitored during three growing seasons using a time series of images with high temporal repetition. Vegetation indices allowed us to follow the crops' development by characterizing the leaf area index (LAI) development throughout the season. Using ground measurements and soil-vegetation-atmosphere-transfer models (SVAT) the evolution of corresponding evapo-transpiration could be computed, allowing us to estimate the total amount of water consumed by the crops. Comparing it to

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the crop water requirement, the efficiency of the irrigation systems can be monitored over the whole area covered by the satellite imagery. As a conclusion, the array of EO techniques available and the foreseeable developments of satellite monitoring of drylands are discussed.

Keywords: Dryland ecosystems, remote sensing, satellite imagery, land use, land cover, leaf area index

1. Background

1.1. THE NEED FOR MONITORING ARID LANDS

In using drylands ecosystems, human societies have adopted various strategies ranging from extensive nomadic pastures to intensive irrigated cash crop production. The sustainability of the various systems from traditional to those using the most advanced agricultural technologies is a key element of the countries' development schemes. Monitoring the condition and performance of the various systems is essential to ensure their efficiency and to suggest and test adaptations to changing conditions (would they be climatic or socio-economic).

1.2. THE CURRENT CHALLENGES

With a large surface to cover, arid areas facing difficulties are often those with limited financial and technical resources to conduct costly regular and reliable ground surveys with trained technical staff. Some point data is usually available, but this is insufficient to assess the land condition and agricultural performance of a district or a region. The majority of arid lands are prone to desertification, and an international environmental treaty has been implemented to tackle this worldwide issue (UNCCD[1]). Within this convention, countries are invited to develop national action plans and methods to assess the progress they make in fighting land degradation. This requires estimating changes in the overall arid land condition of the country. This is indeed easier said than done.

At the same time, the growing demand for water, combined with a long lasting drought in arid regions, calls for accurate assessments of the water budget, particularly in the agricultural sector, which is currently the largest consumer and requested to be more efficient. Here again dedicated monitoring is required to evaluate the water efficiency, particularly of the irrigated areas.

[1] http://www.unccd.int/

1.3. THE POTENTIAL OF EARTH OBSERVATION TECHNIQUES

Faced with the challenges just listed, civil remote sensing technologies have been promoted as an eagerly awaited solution from the moment they were developed. After the initial period of enthusiasm followed by some deception, this technology and its use have matured and remote sensing is now considered as an indispensable environmental monitoring tool (Begni et al., 2006). A large variety of sensors on board satellites launched by a growing number of countries now feeds the receiving and archiving stations with an impressive quantity of data. To give an idea of the current stock of remote sensing imagery, according to the USGS, their archive mainly dedicated to optical imagery (from photographs to Landsat, Spot, AVHRR and MODIS imagery) is currently about 3 million gigabytes (Faundeen et al., 2004). Similarly, the archive maintained by the Spotimage company currently contains about 17 million individual images.

Concerning arid lands, even if this space technology is in the hands of the richer countries, just as internet and mobile phone spread rapidly in developing countries, more and more remotely sensed data is accessible in those countries as well, and its processing can now be done on affordable personal computers with public domain software.

This paper illustrates under which conditions this data can currently contribute to provide land managers with useful information, and will introduce some recommendations for future developments. The challenges in using these data for assessing dryland condition and performance are discussed here around two very different case studies illustrating the range of remote sensing applications for agriculture in those areas (Figure 1). The first one focuses on the need for long term assessment, the other one on quasi-real-time monitoring of crop development for irrigation management.

2. Monitoring long term trends

As part of an international research effort on desertification characterization, mapping and monitoring, the test site of Menzel Habib in southern Tunisia has been subjected to several research projects on the ecology and evolution of rangelands (Escadafal, 2002).

After initial attempts to use Landsat MSS imagery to map its different ecosystems, a program has undertaken the task of using a series of images to assess the changes over time, in order to diagnose the evolution trend and establish if the ecological conditions are worsening, stable or improving. Assessing the trend in land condition requires one to take into account seasonal and inter-annual fluctuations due to climate variability, particularly regarding precipitation, meaning the period considered should cover several decades.

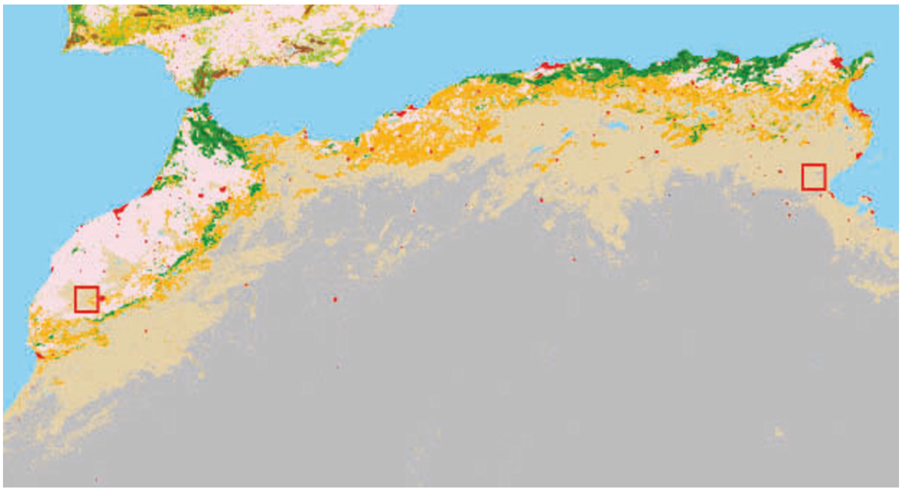


Figure 1. Situation map of the two North African case studies: Tunisian test site (right) and Moroccan test site (left). Notice both are at the northern margin of the Sahara Desert (*background: glc2000 project, JRC*).

It is necessary to encompass a large time span in order to consider long term trends. It appears that the potentially longest series comes from the Landsat satellites, combining the first generation of images from the MSS sensor, with the more recent images of the TM sensor.

Moreover, it is imperative to have imagery of significantly fine resolution in order to establish links with the ground measurements. Low resolution imagery such as from the AVHRR satellite is too coarse for the scale of this detailed study of the changes affecting a test site.

Browsing catalogs of Landsat images reveals that very few 'ancient' images have been archived over the studied area. As a result, it is difficult to build a consistent time series; the dates of acquisition and the time intervals between them cannot be chosen and are too few. As a result of the search effort a series of 27 images (about one per year, based on availability) spanning from 1972 to 2003 has been assembled for the studied test site (Table 1).

TABLE 1. List of the 27 images used in the time series over the Tunisian test site.

Landsat MSS	08/1972 – 02/1973 – 11/1975 – 04/1976 – 06/1976 – 06/1977 – 02/1978 – 07/1979 – 06/1981 – 05/1984 – 09/1987 – 03/1993 –
Landsat TM	03/1986 – 04/1989 – 03/1991 – 07/1991 – 03/1993 – 04/1994 – 03/1995 – 03/1996 – 07/1996 – 03/1997 – 03/1999 – 07/1999 – 09/1999 – 12/1999 – 05/2003

2.1. GEOMETRIC CORRECTION

The image processing chain starts with registration to make the images superimposable. One of the most detailed and contrasted images, part of the middle of the series (recorded in 1985), has been first geocoded using ground GPS measurements and topographic maps. Each image has been warped to this reference image, and finally the TM images (30 m pixel size) have been resampled to the coarser MSS resolution (80 m). The whole set is then available in the local cartographic projection and can easily be overlayed using existing thematic maps and field point observations. Time profiles of pixel values can be computed, but to give them significance, another processing step is required.

2.2. RADIOMETRIC INTERCALIBRATION

To measure changes between dates which are due to modifications of the land surface only, the differences between images due to sensor gain and atmospheric effects must be cancelled (Furby and Campbell, 2001).

Similarly to the previous step, a recent TM image has been selected as a 'reference' and subjected to a conversion into ground reflectance with a dedicated software using satellite calibration and atmospheric parameters from the acquisition day. Ground reflectance spectra collected with a spectro-radiometer have allowed the fine adjustment and validation of this conversion. The other TM images (older) have been also converted to reflectance values using the same software and estimated atmospheric parameters. Using estimations has led to offsets that have been corrected with the pseudo-invariants approach. Therefore a statistical analysis has allowed us to define a subset of 97 radiometrically stable groups of pixels. Finally the MSS subset also has been corrected using the same pseudo-invariant subsets, with specific regressions. In this way the slight spectral difference is taken into account.

At the end of this tedious process, the various images are finally assembled in a stack of inter-comparable measures of land surface reflectances and arranged along a time scale in a manner somewhat comparable to a movie.

2.3. LAND SURFACE CHARACTERISTICS DETECTED IN THE IMAGES

The studied test site is a large plain surrounded by rocky hills. It is covered by steppe vegetation comprised of woody shrubs and annual plants, more and more replaced by cultivation following the settlement of rural populations (extensive olive plantations, and rainfed barley).

A series of ecological ground observations of soil and plant characteristics, combined with reflectance measurements, have allowed us to identify and understand the ground features remotely sensed by the satellite used. A typical natural surface sample will be composed of a desert soil partially covered by clumps of short bushes, with gray, woody stems and branches. Dead litter will also cover the soil, which usually has some typical surface features such as sand veil, desert pavement, or desert crust. Following significant rains (usually in winter), the bushes will grow green shoots and later flowers. Short annual plants will also develop, mature and die in a few weeks.

In brief, the living annual plants (either natural or cultivated) are green only during short periods of time, as are the native woody shrubs. Thus the permanent cover these shrubs ensure, which is an important parameter of the ecosystem condition, can be detected through the vegetation index only at the peak of the growing season; the rest of the time it is more gray, dry plant material. The olive tree density is generally below 10% cover, which is beyond the threshold of detection by vegetation indices.

As a result, the land surface of the studied area, as viewed by the satellites, is predominantly composed of bare soil (from 70% to 90%), a few living plants (5–25%), and some litter (0–5%). Except during the 'green' period, it shows very little green material.

The collected spectroradiometric field measurements allowed us to analyze the main spectral feature of the land surface components (Figure 2). Three main results can be summarized:

1. Soils show the largest variations in reflectance from dark rocky soils (30%) to very bright gypsiferous crusted soils (80%).
2. Soil color varies with the nature of surface material such as sand sheet, and is mainly due to absorption by iron oxides in the short visible spectral domain (blue and green).
3. Vegetation has mainly a darkening effect (20% reflectance) and a weak red/near-infrared contrast (except in the short greening period).

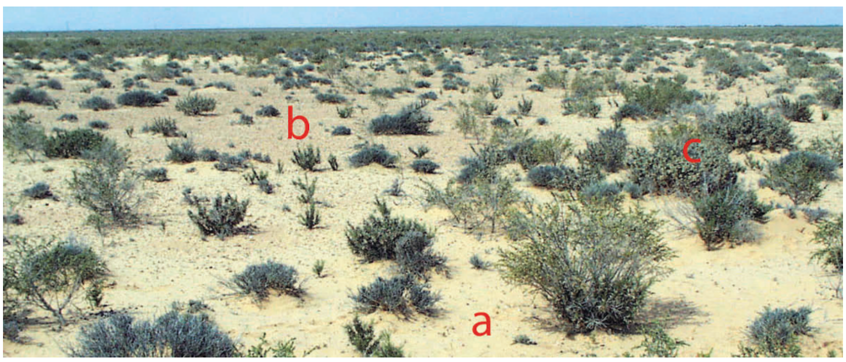


Figure 2. Typical land surface sample of the Tunisian test site: (a) *bright yellowish sandy soil deposit*, (b) *darker loamy soil*, (c) *woody shrub, partially green*.

From this description its now more obvious why the vegetation indices derived from remote sensing are not well suited to monitor the environment of southern Tunisia (Kennedy, 1989) despite their widespread use, including in drylands (Justice and Hiernaux, 1986; Anyamba and Tucker, 2005, e.g.). The classical use of the contrast between the red and near-infrared reflectance, such as in the NDVI, is only able to detect green cover over 25–30%. This is happening in the area with only sporadic native vegetation, and as well on rain-fed agricultural fields. The tree or seed density is generally very low, a typical dry farming technique. Only on hilly surfaces do rain harvesting techniques allow higher densities, but they are not developed in the studied plain.

2.4. DETECTING LONG TERM LAND SURFACE CHANGES

As a result of the results of ground data analysis, three main remotely sensed parameters have been computed for each image:

1. Classical vegetation index (NDVI) to detect active vegetation
2. Brightness index (mean of the sum of the three visible bands) related to the soil surface type and vegetation density
3. Color index based on the contrast between blue-green and red bands (redness index, Escadafal and Huete, 1991) varying with soil surface material (such as sand deposits)

Note that only bands common to MSS and TM sensors have been used (visible and NIR) to allow similar treatments across the whole series.

Bearing in mind that the date of each individual 'yearly' satellite image could not be chosen at a specific moment during the season, the values of the vegetation index are of limited interest when considering pluri-annual, long term trends. Thus, the two last indices were found the most relevant, and their evolution through time has been used as a criterion for the detection of long term changes.

Using a simple linear trend analysis, pixels have been classified according to their overall increase/decrease in redness and brightness indices. Figure 3 illustrates the concept, which has been applied to the whole series (see Escadafal et al., 2005).

Brightness index computed for a given date over the test area
(*TM image resampled at 80 m*)

-a-

Temporal profile of brightness for a given pixel
(*across the series of images numbered from 0 to 26*)

-b-

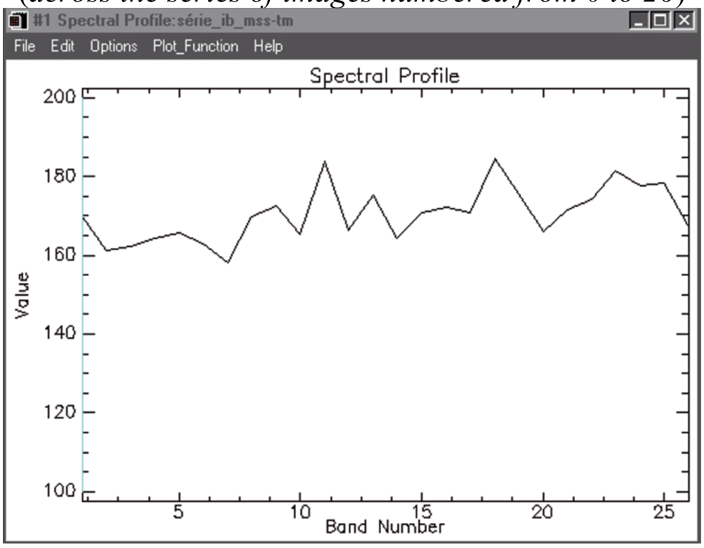


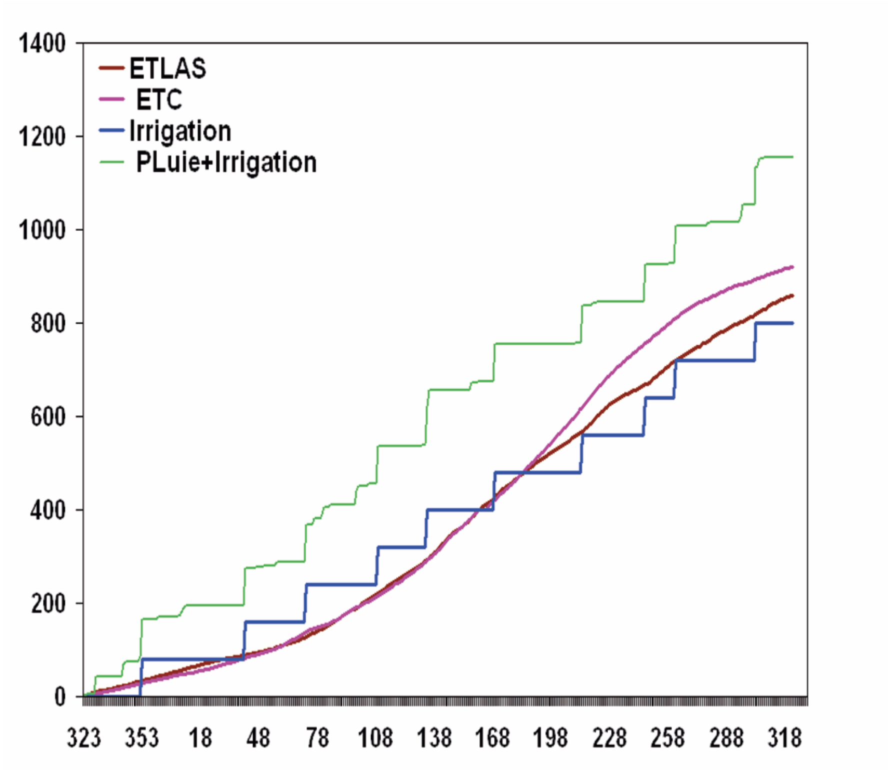
Figure 3. Principle of long term trend analysis for land surface brightness (*trend will be computed for each pixel from its temporal profile*).

3. Quasi-real time crop growth monitoring

In a second case, the irrigated agricultural plain of the Marrakesh region in southern Morocco has been subjected to intensive monitoring by high resolution satellites in the context of recent research projects (Chehbouni et al., 2008). The rationale of these project lies within the fact that in the Mediterranean region, about 85% of available water is used for irrigation agriculture with an average efficiency not exceeding 40% to 50%.

Figure 4 presents an example of inefficiency of irrigation over olive orchard fields in Morocco where, despite the fact that the total water applied exceeds the crop water requirement, stress is observed during a crucial period.

Therefore, the first step toward sustainable management of water resources in these regions is a controlled use of irrigation water. In other words, it is important to provide the farmers and irrigation managers with the following crucial information: when to irrigate and how much water to apply. Providing



X axis, day of the year
Y axis, cumulative water in millimeters

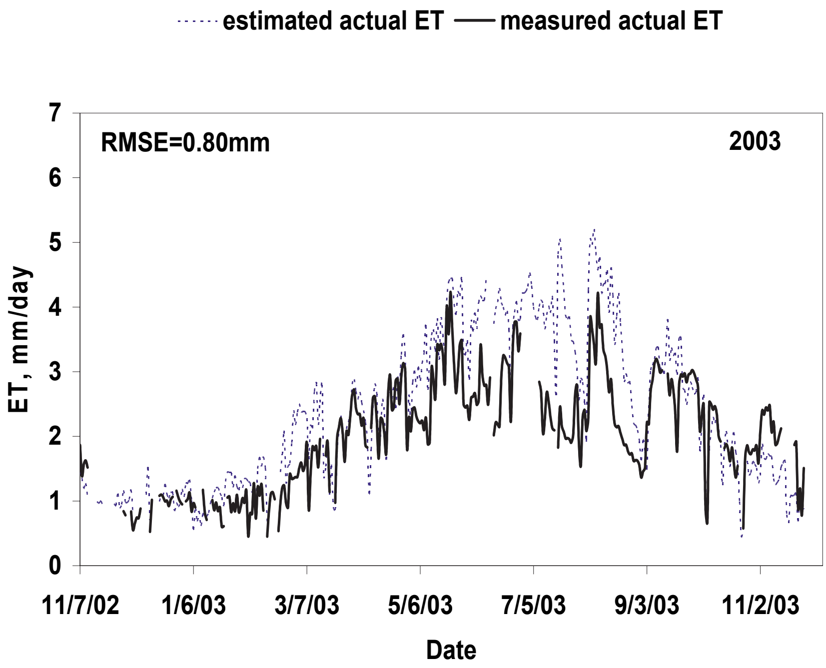
Figure 4. Comparison of cumulated evapo-transpiration and irrigation over an olive orchard field (from Ezzahar et al., 2007).

such information at different space-time scales is not trivial. This requires the combination of process models and procedures to feed them with remotely sensed data. These models need also to be validated using ground based measurements of water need and consumption for different crops.

In this general context, a comprehensive experimental plan has been designed where measurements of water and energy balance variables have been made over different crops within the Haouz plain. Measurements over each of the eight sites making up the dominant types of vegetation in the region (wheat, oranges, and olives) have been made. This includes basic meteorological data, surface fluxes using eddy covariance systems and scintillometers (over four sites), soil moisture and temperature, surface temperature and reflectance, vegetation cover, Leaf Area Index and yield (Ezzahar et al., 2007).

Several types of process models have been implemented during the course of the project. These models range from the most simple (FAO-56) to the most complex one (i.e., SVATs). The results show that the physically based SVATs, such as ICARE (Gentine et al., 2007), provide the best estimates of surface fluxes over all sites, but they require several input parameters which are not routinely available at the appropriate time scale. We are therefore faced here with the dilemma of the choice of a SVAT model to accurately describe the surfaces fluxes in semi-arid regions. Realizing that no single model will be the "best" choice for all possible applications, the choice of model in any given situation is a trade-off between the desirable but incompatible traits of realism and simplicity.

Despite these problems, we adopt the strategy of using complex and physically based models such as ICARE to test the realism of a simplified model such as FAO-56, which is widely used for operational purposes. In this regard we find that the crop coefficients provided in the FAO-table are not appropriate over this region. One promising avenue is to establish relationships between high resolution satellite based vegetation index and the crop coefficient over different vegetation types. This approach has been successfully implemented over several wheat fields (Er-Raki et al., 2007). However, despite the fact that this approach led to a noticeable improvement in the performance of the FAO method, some discrepancies between observed and simulated ET remained. A detailed analysis of the reason for these discrepancies using ICARE showed that the water balance module in the FAO method is rather simple if not overly simplistic. To overcome this problem, we developed an original procedure based on the assimilation of high resolution thermal infrared (ASTER) based ET in the FAO method, which allowed for adjusting some of the coefficient of the water balance module. The results presented in Er-Raki et al. (2008) are very promising (Figure 5).



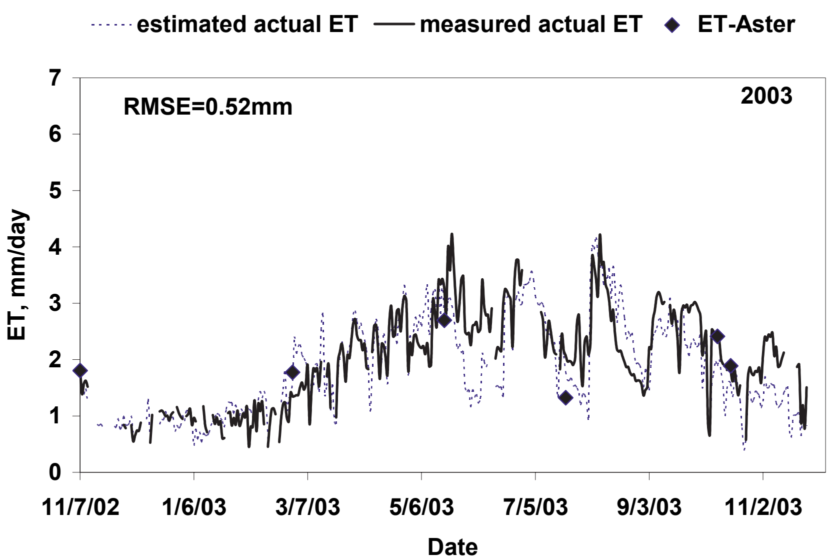


Figure 5. Improvement of the simulation of evapo-transpiration of a wheat field by assimilating few thermal infrared measurements. *Top: simulation of ET with the FAO method versus predicted. Bottom: improved simulated ET with assimilation of ASTER data.* (From Er-Raki et al., 2008.)

4. Conclusion: the future of arid lands observation with satellites

4.1. MISSING INFORMATION

When considering satellite image analysis for arid land condition assessment (degradation/stability/improvement), and while looking at decoupling the seasonal from the long term trends there is a need to combine the two types of data available, some with high temporal resolution and others with spatial resolution, as none is sufficient by itself. Raw data of this kind is available, but the processing to combine the two and provide the missing information is yet to be developed.

When looking at the water consumption by crops, the overall crop development gives a fair estimate of the water used by the plants at the season level. However, what is more needed is a method of monitoring crop water needs in order to irrigate efficiently, which means with the right amount at the right time. A simple approach with NDVI monitoring the foliage greenness is insufficient, as water stressed crops will show change in greenness only after a period of stress long enough to cause damage to the foliage. If we wait for that signal to detect the need for irrigation, it will come far too late. A more sensible method is to monitor the foliage temperature, as a well watered, unstressed crop has a canopy temperature lower than that of the air.

As shown above, the combination of high resolution data in both VIS-NIR and TIR represents a promising avenue for improving estimates of water consumption in these water scarce areas. Unfortunately, in contrast to instruments in VIS-NIR, which will have substantial development the near future (Venμs, Sentinel, …), the large space agencies (from EU, US, and Japan) do not seem interested in developing operational high resolution satellites in TIR. On the contrary, NASA seems ready to remove TIR bands in future LANDSAT-like satellites. We can only hope that some other active space agencies will take on the challenge of providing this much needed high resolution thermal infrared imagery.

4.2. PROSPECTIVE APPLICATIONS

It can be concluded that information valuable for monitoring arid lands exists, but it is not easily available. Often it is difficult to access due to inadequacy of the distribution system, poor cataloging, high charges, lack of common standard format, and the tedious procedure of obtaining usable information, such as ground reflectance.

Ground information for validation is also rather poor. Very little long term test site data at a scale compatible with remote sensing are available, and the lack of standardization is even more blatant. A quick and easy assessment of drylands condition with remote sensing still sounds like a researchers dream, even if several studies (including the ones cited in this paper) have demonstrated potential.

Only a large effort on the part of the community towards an internationally concerted network, such as the proposed Dryland Observation Systems,[2] will allow researchers to use existing and future data collected by Earth observation technologies at their full potential and to combine them efficiently with other measurements and ground observations.

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BIODIVERSITY OF THE ARAL SEA AND ITS IMPORTANCE TO THE POSSIBLE WAYS OF REHABILITATING AND CONSERVING ITS REMNANT WATER BODIES

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Abstract. The Aral Sea, despite being the 4th largest lake in the world up to 1960, has now split into six separate water bodies. This break-up and desiccation resulted overwhelmingly from upstream irrigation withdrawals from the two main influent rivers, the Syr Darya and the Amu Darya. The negative effects on both the lake's ecosystem due to declining water level and increasing salinity, as well as the profound socioeconomic and human impacts to the riparian populations are well documented. This paper focuses on the conservation and rehabilitation efforts of the remnant water bodies with a focus on four key areas: the Northern (Small) Aral and its ecosystem; the Southern (Large) Aral and its ecosystem; the delta and deltaic water bodies of the Syr Darya; and the delta and deltaic water bodies of the Amu Darya. It is encouraging to note the reversal of degradation in the Northern Aral after the creation of a dike at Berg's Strait in 1992. The dike washed out in 1999 but has been replaced with a new structurally sound dike. The water level in the Northern Aral has increased several meters and salinity is returning to levels that can sustain the pre-1960 ecosystem. However, much less success has been seen regarding the Southern Aral, which continues its retreat and hypersalinization. There have been recent efforts also in the

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deltas and deltaic regions of the Syr Darya and Amu Darya, with the rehabilitation of Sudochie Lake perhaps being the best known. All of these restoration projects are critiqued in this paper and recommendations for future actions are made.

Keywords: Aral Sea, deltaic water bodies, lake basin management, rehabilitation, saline lakes, salinity, osmoregulation

1. The Aral Sea and its biodiversity

The Aral Sea was the 4th largest lake in the world by water surface area in 1960. At that time its area was 67,499 km^2 (Large Aral 61,381 km^2, Small Aral 6,118 km^2) and volume was 1,089 km^3 (Large Aral 1,007 km^3, Small Aral 82 km^3). The Aral Sea was +53.4 m above ocean level with maximum depth 69 m. It was a slightly saline lake with average salinity about 10 g/L.

The Aral Sea was inhabited by about 12 species of fishes and about 160 species of free-living invertebrates excluding Protozoa and small-size Metazoa as listed in Table 1 (Atlas of the Aral Sea invertebrates, 1974).

TABLE 1. Aboriginal fishes and free-living invertebrates in the Aral Sea (Atlas of the Aral Sea invertebrates, 1974).

Species	Type of osmoregulation
Coelenterata	
Protohydra leuckarti Greef, 1970	A3
Turbellaria	
Mecynostomum agile (Beklemischev, 1927)	A3
Macrostomum hystricinum Beklemischev, 1927	A3
M. minimum (Luther, 1947)	A3
Promonotus orientalis Beklemischev, 1927	A3
Kirgisella forcipata Beklemischev, 1927	A3
Gieysztoria bergi (Beklemischev, 1927)	A3
Byrsophlebs geniculata Beklemischev, 1927	A3
Beklemischeviella contorta (Beklemischev, 1927)	A3
Phonorhynchoides flagellatus Beklemischev, 1927	A3
Gyratrix hermaphroditus Ehrenberg, 1831	A3
Pontaralia relicta (Beklemischev, 1927)	A3
Placorhynchus octaculeatus ssp. *dimorphis* (Karling, 1931)	A3
Nematodes	
Adoncolaimus aralensis Filipjev, 1923	C1
Rotatoria	

Species	Type of osmoregulation
Eosphora ehrenbergi Weber, 1918	C1
Trichocerca (*Diurella*) *heterodactyla* Tschugunoff, 1921	C1
T. (*D.*) *similis* (Wierzejski, 1893)	C1
T. (*D.*) *porcellus* (Gosse, 1851)	C1
T. (s. str.) *elongata* (Gosse, 1896)	C1
T. (s. str.) *pusilla* (Lauterborn, 1898)	C1
T. (s. str.) *longiseta* (Schrank, 1802)	C1
T. (s. str.) *caspica* Tschugunoff, 1921	C1
Synchaeta stylata Wierzejski, 1893	C1
S. vorax Rousselet, 1902	C2
S. tremula (Müller, 1786)	C2
S. pectinata Ehrenberg, 1832	C1
Polyarthra euryptera Wierzejski, 1891	C1
P. luminosa Kutikova, 1962	C1
P. vulgaris Carlin, 1943	C1
P. longiremis Carlin, 1943	C1
Lindia torulosa Dujardin, 1841	C2
Encentrum limicola Otto, 1963	C2
Asplanchna priodonta Gosse, 1850	C1
A. girodi Guerne, 1888	C1
Brachionus angularis Gosse, 1851	C1
B. calyciflorus Pallas, 1776	C1
B. quadridentatus Hermann, 1783	C2
B. plicatilis Müller, 1786	C2
B. rubens Ehrenberg, 1838	C1
B. urceus (Linnaeus, 1758)	C1
Platyias quadricornis (Ehrenberg, 1832)	C1
P. palustris (Müller, 1786)	C1
Keratella cochlearis (Gosse, 1851)	C2
K. tropica (Apstein, 1907)	C2
K. quadrata (Müller, 1786)	C2
K. valga (Ehrenberg, 1834)	C2
Notholca squamula (Müller, 1786)	C2
N. acuminata (Ehrenberg, 1832)	C2
Kellicottia longispina (Kellicott, 1879)	C1
Euchlanis dilatata Ehrenberg, 1832	C1
E. triquerta Ehrenberg, 1838	C1
Trichotria pocillum (Müller, 1776)	C1
T. tetractis (Ehrenberg, 1830)	C1
Mytilina ventralis (Ehrenberg, 1832)	C1
Lecane (*Lecane*) *luna* (Müller, 1776)	C1

Species	Type of osmoregulation
L. (*L.*) *ungulata* (Gosse, 1887)	C1
L. (*Monostyla*) *lamellata* (Daday, 1893)	C1
L. (*M.*) *stenroosi* (Meissner, 1908)	C1
L. (*M.*) *bulla* (Gosse, 1851)	C1
L. (*M.*) *lunaris* (Ehrenberg, 1832)	C1
Colurella obtusa (Gosse, 1886)	C1
C. adriatica Ehrenberg, 1831	C2
C. uncinata (Müller, 1773)	C1
C. colurus (Ehrenberg, 1830)	C2
Hexarthra fennica (Levander, 1892)	C2
H. oxyuris (Zernov, 1903)	C2
H. mira (Hudson, 1871)	C1
Testudinella patina (Hermann, 1783)	C2
T. bidentata (Ternetz, 1892)	C1
Filinia longiseta (Ehrenberg, 1834)	C1
Collotheca mutabilis (Hudson, 1885)	C1
Oligochaeta	
Aeolosoma hemprichi Ehrenberg, 1828	C1
Nais elingius Müller, 1773	C1
N. communis Piguet, 1906	C1
Paranais simplex Hrabe, 1936	C1
Amphichaeta sannio Kallstenius, 1892	C1
Chaetogaster sp.	C1
Limnodrilus helveticus Piguet, 1923	C1
Potamothrix bavaricus (Oeschmann, 1913)	C1
Psammorhyctides albicola (Michaelsen, 1901)	C1
Lumbriculus lineatus (Müller, 1771)	C1
Cladocera	
Diaphanosoma brachyurum Lievin, 1848	C1
Chydorus sphaericus (O. F. Müller, 1785)	C2
Alona rectangula G. Sars, 1861	C2
Bosmina longirostris (O. F. Müller, 1785)	C2
Daphnia longispina (O. F. Müller, 1776)	C2
Ceriodaphnia reticulata (Jurine, 1820)	C2
C. cornuta G. Sars, 1885	C2
C. pulchella G. Sars, 1862	C2
Moina mongolica Daday, 1901	D4
M. micrura Kurz, 1874	C2
Podonevadne camptonyx (G. Sars, 1897)	D3
P. angusta (G. Sars, 1897)	D1
Evadne anonyx G. Sars, 1897	D1

Species	Type of osmoregulation
Cercopagis pengoi aralensis M.-Boltovskoi, 1971	C2
Copepoda	
Phyllodiaptomus blanci (Guerne et Richard, 1896)	C1
Arctodiaptomus salinus (Daday, 1885)	B1
Halicyclops rotundipes aralensis Borutzky, 1971	B1
Cyclops vicinus Uljanin, 1875	C1
Acanthocyclops viridis (Jurine, 1820)	C1
Mesocyclops leuckarti (Claus, 1857)	C1
Thermocyclops crassus (Fischer, 1853)	C1
Harpacticoida	
Halectinosoma abrau (Kritchagin, 1873)	B2
Schizopera aralensis Borutzky, 1971	B2
S. jugurtha (Blanchard et Richard, 1891)	B2
S. reducta Borutzky, 1971	B2
Nitocra lacustris (Schmankewitsch, 1875)	A3
N. hibernica (Brady, 1880)	C1
Mesochra aestuarii Gurney, 1921	B2
Onychocamptus mohammed (Blanchard et Richard, 1891)	B2
Cletocamptus retrogressus Schmankewitsch, 1875	A3
C. confluens (Schmeil, 1894)	A3
Limnocletodes behningi Borutzky, 1926	C2
Nannopus palustris Brady, 1880	B2
Enchydrosoma birsteini Borutzky, 1971	A3
Leptocaris brevicornis (Van Douwe, 1905)	B2
Paraleptastacus spinicauda Noodt, 1954	A3
Ostracoda	
Darwinula stevensoni (Brady et Robertson, 1870)	C2
Candona marchica Hartwig, 1899	C1
Cyclocypris laevis (O. F. Müller, 1776)	C2
Plesiocypris newtoni (Brady et Robertson, 1870)	C1
Cyprideis torosa (Jones, 1850)	D4
Amnicythere cymbula (Livental, 1929)	D1
Tyrrhenocythere amnicola donetziensis (Dubowsky, 1926)	D1
Limnocythere (*Limnocythere*) *dubiosa* Daday, 1903	
L. (*L.*) *inopinata* (Baird, 1850)	C2
L. (*Galolimnocythere*) *aralensis* Schornikov, 1973	D1
Loxoconchissa (*Loxocaspia*) *immodulata* (Stepanaitys, 1958)	
Malacostraca	
Dikerogammarus aralensis (Uljanin, 1875)	B1
Hydracarina	
Eylais rimosa Piersig, 1899	C1

Species	Type of osmoregulation
Hydriphantes s. str. *Crassipalpis* Könike, 1914	C1
H. (*Polyhydriphantes*) *flexuosus* (Köenike, 1885)	C1
Hydrodroma despiciens (O. Müller, 1776)	C1
Limnesia undulata (O. F. Müller, 1776)	C1
Arrenurus s. Str. *Tricuspidator* (O. F. Müller, 1776)	C1
Copidognathus (s. str.) *oxianus* Viets, 1928	C1
Bivalvia	
D. polymorpha aralensis (Andrusov, 1897)	C2
D. p. obtusicarinata (Andrusov, 1897)	C2
D. caspia caspia Eichwald, 1829	C2
D. c. pallasi (Andrusov, 1897)	C2
Cerastoderma rhomboides rhomboides (Lamarck, 1819)	A3
C. isthmicum Issel, 1869	A3
H. vitrea bergi Starobogatov, 1971	A3
H. minima sidorovi Starobogatov, 1971	A3
H. m. minima (Ostroumoff, 1907)	A3
Gastropoda	
Theodoxus pallasi Lindholm, 1924	A3
Caspiohydrobia conica (Logvinenko et Starobogatov, 1968)	A3
C. husainovae Starobogatov, 1971	A3
Pisces	
Cyprinus carpio Linnaeus, 1758	C1
Rutilus rutilus aralensis Berg, 1916	C1
Abramis brama orientalis Berg, 1949	C1
Abramis sapa bergi natio *aralensis* Tjapkin, 1939	C1
Aspius aspius taeniatus (Eichwald, 1831)	C1
Barbus brachycephalus brachycephalus Kessler, 1872	C1
Capoetobrama kuschakewitschi (Kessler, 1872)	C1
Pelecus cultratus (Linnaeus, 1758)	C1
Scardinius erythrophthalmus (Linnaeus, 1758)	C1
Esox lucius Linnaeus, 1758	C1
Silurus glanis Linnaeus, 1758	C1
Gymnocephalus cernuus (Linnaeus, 1758)	C1
Perca fluviatilis Linnaeus, 1758	C1
Zander lucioperca (Linnaeus, 1758)	C1
Chalcalburnus chalcoides aralensis (Berg, 1923)	C1
Salmo trutta aralensis	D3
Pungitius platygaster aralensis (Kessler, 1877)	D3
Acipenser nudiventris (Lovetzky, 1828)	D3

Since 1960 the Aral Sea has steadily become shallower, owing overwhelmingly to water withdrawals upstream for irrigation. By 2007 the Aral was around 13,958 km^2 (21% of 1960), volume – 102 km^3 (9% of 1960). The Large Aral was 10,700 km^2 (17% of 1960) and had a volume of 75 km^3 (8% of 1960). Salinity of the Large Aral ranged from 100 g/L to well above that figure. Similar values for the Small Aral are 3,258 km^2 (53% of 1960), 27 km^3 (33% of 1960) with average salinity at about 10 g/L.

Prior to introduction of fishes and free-living invertebrates to the Aral Sea that started in the 1920s, the following aboriginal free-living animals were present: Fishes – 12, Coelenterata – 1, Turbellaria – 12, Rotatoria – 58, Oligohaeta – 10, Cladocera – 14, Copepoda – 7, Harpacticoida – 15, Ostracoda – 11, Malacostraca – 1, Hydracarina – 7, Bivalvia – 9, Gastropoda – 3. Total – 160. Protozoa and some other small-size Metazoa are not included.

Between the middle of the nineteenth century and 1961 the shape and salinity of the Aral Sea remained practically unchanged. We must note, however, that due to intended and accidental introductions that started in the 1920s the number of free-living animals grew substantially. In the Aral Sea appeared: Fishes – 21, Mysidacea – 5, Decapoda – 3, Copepoda – 3, Polychaeta – 1, Bivalvia – 4 for a total of 37 species (Table 2).

Originally in the Aral Sea there were freshwater, transitional freshwater-brackish water, brackish water and transitional brackish water-marine ecosystems. Brackish water ecosystems occupied the largest area (Figure 1). By the end of 1980s, due to salinity growth, marine ecosystems appeared in the Aral Sea and occupied the largest area instead of brackish water ecosystems (Figure 2). Now all parts of the Large Aral are occupied by hyperhaline ecosystems. In the Small Aral transitional brackish water-marine ecosystems are prevailing due to salinity decrease (Figures 3 and 4).

Abra ovata and *Nereis diversicolor* introduced by man are of great importance for fish nutrition. *Rhithropanopeus harrisii tridentata* was introduced accidentally and disturbs lake sediments.

Since the end of the 1980s, when the level dropped by about 13 m and reached about +40 m, the Aral Sea divided into the Large and Small Aral with area 40,000 km^2 (60% from 1960); volume 333 km^3 (33% from 1960); salinity 30 g/L (three times higher than in 1960).

In both newly created lakes salinity increased (Table 3) and under these new conditions the following free-living animals could survive: Fishes – 10; Rotatoria – 3; Cladocera – 2; Copepoda – 2; Ostracoda – 1; Decapoda – 2; Bivalvia – 2; Gastropoda – >2; Polychaeta – 1 for a total of >25 (Figures 5–8).

After the Aral Sea division, its volume has decreased from 1,000 km^3 to 400 km^3 by 2001 and to 108 km^3 by 2005 with the Large Aral Sea volume (2005) at 85 km^3 and the Small Aral Sea volume (2005) at 23 km^3 (Figure 9).

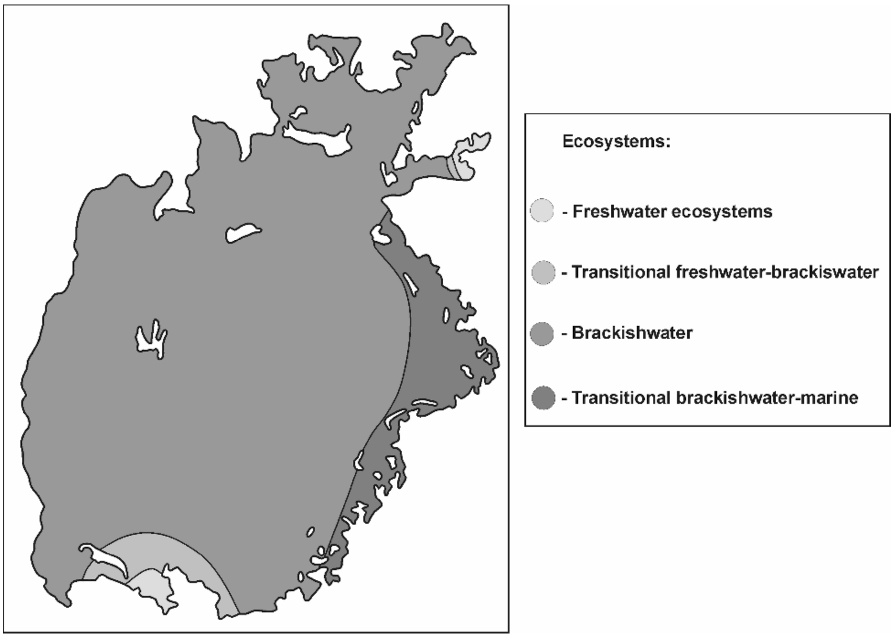

Figure 1. Ecosystems in relation to salinity before Aral Sea salinization.

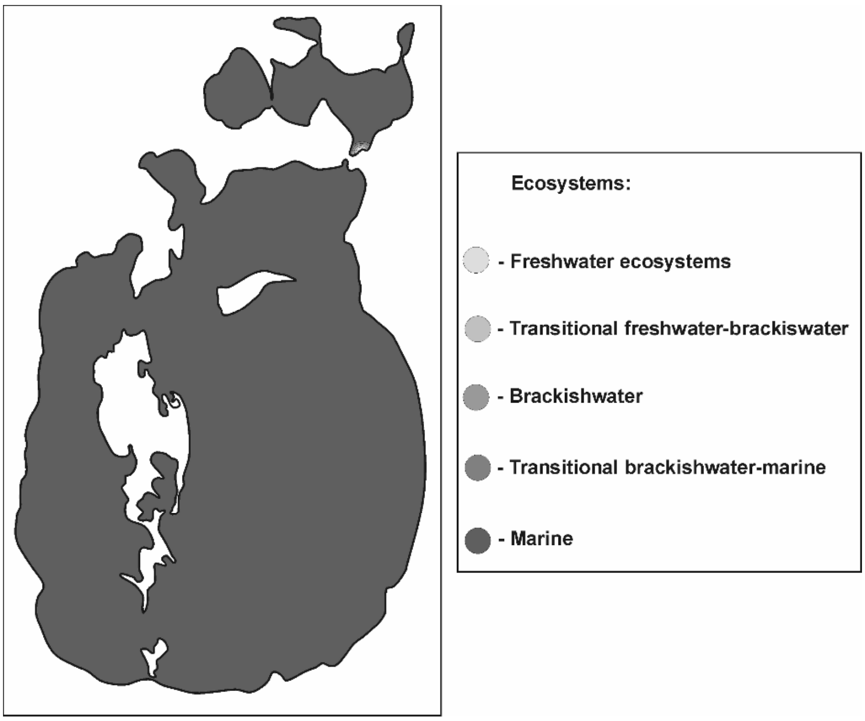

Figure 2. Ecosystems in relation to salinity at Aral Sea division.

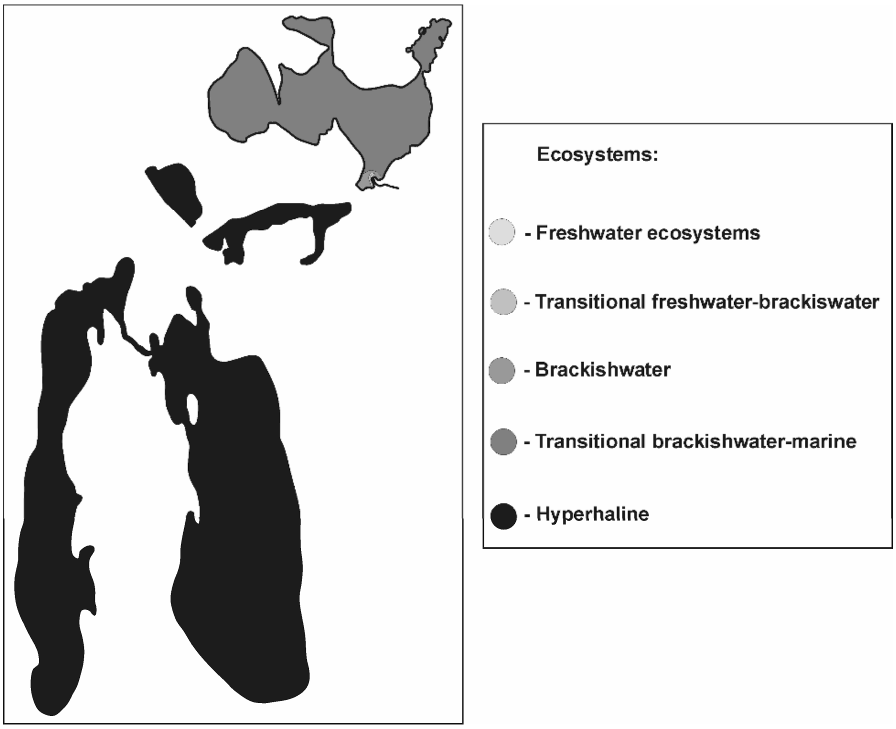

Figure 3. Ecosystems in relation to salinity now.

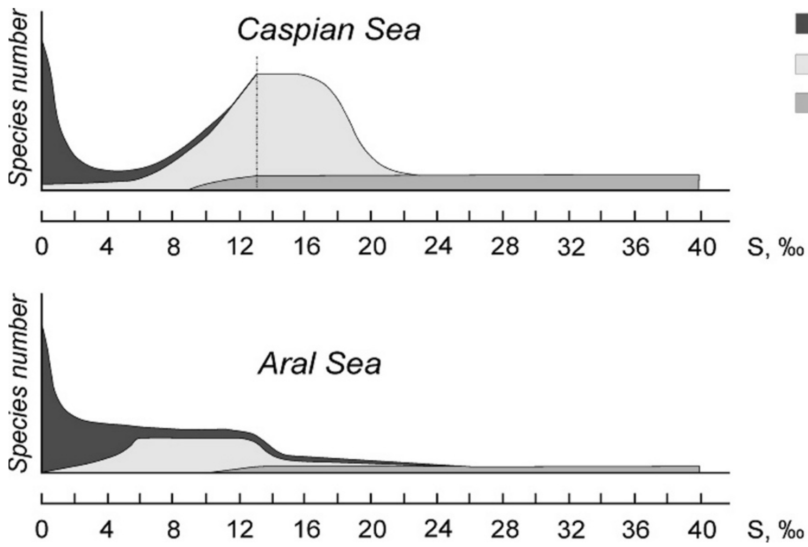

Figure 4. Scheme of aquatic fauna pattern change in the Caspian and Aral seas (by: Zenkevich, 1977; Andreeva and Andreev, 2001 with additions and corrections) 1 – freshwater, 2 – brackish-water, 3 – marine species.

TABLE 2. Alien fishes and free-living invertebrates in the Aral Sea (by: Aladin et al., 2004).

Taxon	Source	Year	Status	Status in the 1990s–2000s	Way	Impact	Type of osmo-regulation
Pisces							
Alosa caspia (Eichwald, 1838)	Caspian	1929–1932	–	–	A	0	D3
Acipenser stellatus Pallas, 1771	Caspian	1927–1934; 1948–1963	–	–	A	0	D3
Acipenser nudiventris derjavini Borzenko, 1950	Ural River	1958	–	–	A	–	D3
Acipenser guldenstadti Brandt et Ratzeburg, 1833	?	1978–1980	R	–	A	0	D3
Clupea harengus membras (Linnaeus, 1758)	Baltic Sea	1954–1959	R	?	A	+	D3
Liza auratus (Risso, 1810)	Caspian	1954–1956	–	–	A	0	E
Liza saliens (Risso, 1810)	Caspian	1954–1956	–	–	A	0	E
Ctenopharyng-odon idella (Valenciennes, 1844)	China	1960–1961	C	–	A	+	C1
Hypophtalmic-hthys molifrix (Valenciennes, 1844)	China	1960–1961	C	–	A	+	C1
Aristichtys nobilis (Richardson, 1844)	China	1960–1961	R	–	A	+	C1
Platichthys flesus (Linnaeus, 1758)	Sea of Azov	1979–1987	C	C	A	+	E

Taxon	Source	Year	Status	Status in the 1990s–2000s	Way	Impact	Type of osmo-regulation
Mylopharyng-odon piceus (Richardson, 1845)	China	1960–1961	C	–	A+	0	C1
Syngnatus abaster caspius Eichwald	Caspian	1954–1956	R	–	A+	–	E
Atherina boyeri caspia Eichwald, 1838	Caspian	1954–1956	N	R	A+	–	E
Knipowitschia caucasicus (Berg, 1916)	Caspian	1954–1956	N	?	A+	–	D3
Neogobius fluviatilis (Pallas, 1811)	Caspian	1954–1956	N	?	A+	–	D3
Neogobius melanostomus (Pallas, 1811)	Caspian	1954–1956	N	–	A+	–	D3
Neogobius syrman (Nordmann, 1840)	Caspian	1954–1956	R	–	A+	–	D3
Proterorchinus marmoratus (Pallas, 1811)	Caspian	1954–1966	R	?	A+	–	D3
Neogobius kessleri (Gunter, 1861)	Caspian	1954–1956	R	–	A+	–	D3
Ophicephalus (*Channa*) *argus* Cantor, 1842	Kara–Kum canal	1960s	C	C	A+	+	C1
Branchiopada							
Artemia salina (Linnaeus, 1758)*	Aral region	1990s–2000s	N	N	N	+	D4
Ostracoda							
Eucypris inflata G.O. Sars, 1903*	Aral region	1990s–2000s	N	N	N	+	D4

Taxon	Source	Year	Status	Status in the 1990s–2000s	Way	Impact	Type of osmo-regulation
Mysidacea							
Paramysis baeri (Czerniavsky, 1882)	Don River	1958–1960	?	–	A	0	C2
Paramysis lacustris (Czerniavsky, 1882)	Don River	1958–1960	N	In deltas	A	+	C2
Paramysis intermedia (Czerniavsky, 1882)	Don River	1958–1960	N	–	A	+	C2
Paramysis ullskyi (Czerniavsky, 1882)	Don River	1958–1960	R	–	AC	+	C2
Limnomysis benedeni (Czerniavsky, 1882)	?	?	R	–	AC	+	C2
Decapoda							
Palaemon elegans Rathke, 1837	Caspian	1954–1966	N	N	A+	?	B1
P. adspersus Rathke, 1837	Caspian	1954–1966	?	–	A+	?	B1
Rhithropanopeus harrisii tridentata (Maitland, 1874)	Sea of Azov	1965, 1966,	N	N	A+	+	B2
Copepoda							
Calanipeda aquaedulcis Kritschagin, 1873	Sea of Azov	1965, 1966–1970	N	N	A	+	B1
Heterocope caspia Sars, 1897	?	1971	–	–	A	0	?
Acartia clausi Giesbrecht, 1889	?	1985, 1986	–	–	A	0	B1
Polychaeta							

Taxon	Source	Year	Status	Status in the 1990s–2000s	Way	Impact	Type of osmo-regulation
Hediste diversicolor (Müller, 1776)	Sea of Azov	1960–1961	N	N	A	+	A3
Bivalvia							
Abra ovata (Philippi, 1893)	Sea of Azov	1960, 1961, 1963	N	N	A	+	A3
Monodacna colorata (Eichwald, 1839)	?	1964, 1965	–	–	A	0	A3
Mytilus galloprovinci-alis Lamarck, 1819	Sea of Azov	1984–1986	–	–	A	0	A3
Mya arenaria Linnaeus, 1758	Sea of Azov	1984–1986	–	–	A	0	A3

Way of introduction: A – acclimatization, AC – by accident, A+ – incidentally at planned introduction, N – naturally.

Status: R – rare, N – numerous, C – commercial.

Impact: – negative, + positive, 0 no effect, ? unknown.

[*]Only in the Large Aral.

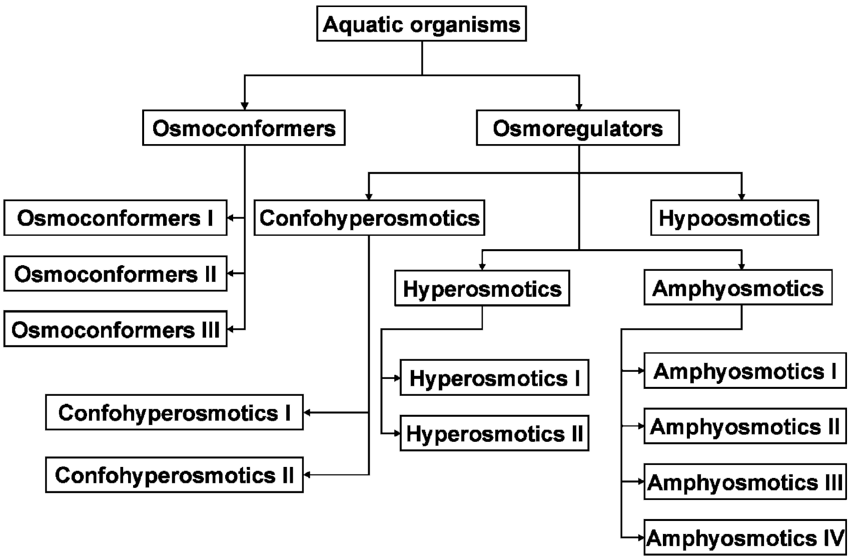

Figure 5. Classification of osmoconformers and osmoregulators.

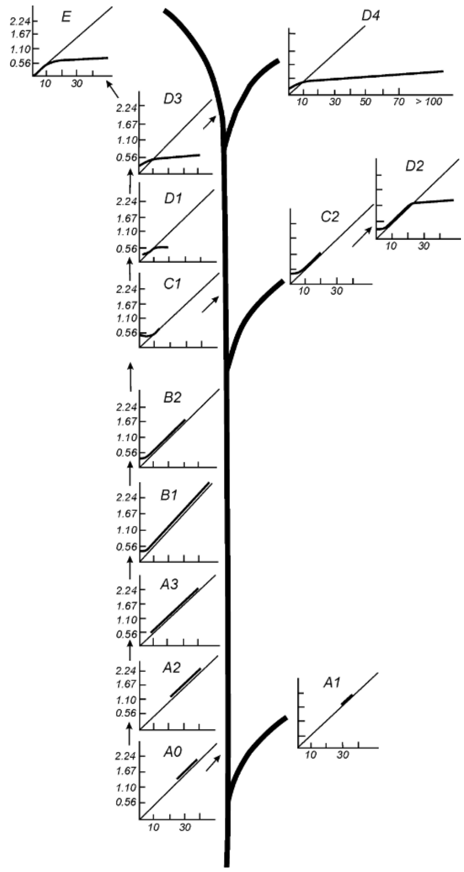

Figure 6. Evolution of all known types of osmoregulation (by: Aladin, 1996):

A0 – Hypothetic ancestral osmoconformer; A1 – Stenohaline marine hydrobionts (osmoconformers I) – 30–36‰; A2 – Marine hydrobionts (osmoconformers II) – 20–40‰; A3 – Euryhaline marine hydrobionts (osmoconformers III) – 8–40‰; B1 – Widely euryhaline marine hydrobionts (confohyperosmotics I) – 3–50‰ B2 – Brackish water hydrobionts of marine origin (confohyperosmotics II) – 0–30‰; C1 – Freshwater hydrobionts (hyperosmotics I) – 0–8‰; C2 – Brackish water hydrobionts of freshwater origin (hyperosmotics II or secondary confohyperosmotics) – 0–20‰; D1 – Some Caspian Brackish water hydrobionts (amphiosmotics I) – 0–20‰; D2 – Some euryhaline Australian hydrobionts of freshwater origin (amphiosmotics II) – 0–50‰; D3 – Euryhaline hydrobionts of freshwater origin (amphiosmotics III) – 0–50‰; D4 – Widely euryhaline hydrobionts of freshwater origin (amphiosmotics IV) – 0–300‰; E – Euryhaline marine hydrobionts of freshwater origin (hypoosmotics) – 8–50‰.

After the Aral Sea division salinity in the Large Aral continued to rise and reached 90 g/L (western part) and 160 g/L (eastern part) in 2005, while in the Small Aral it decreased and reached 17 g/L in 2005.

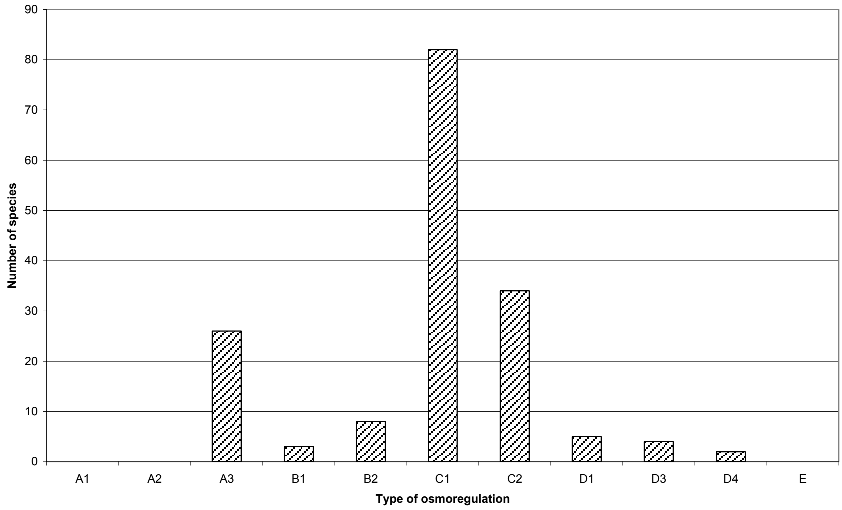

Figure 7. Number of different types of osmoregulation in aboriginal fishes and free-living invertebrates in the Aral Sea.

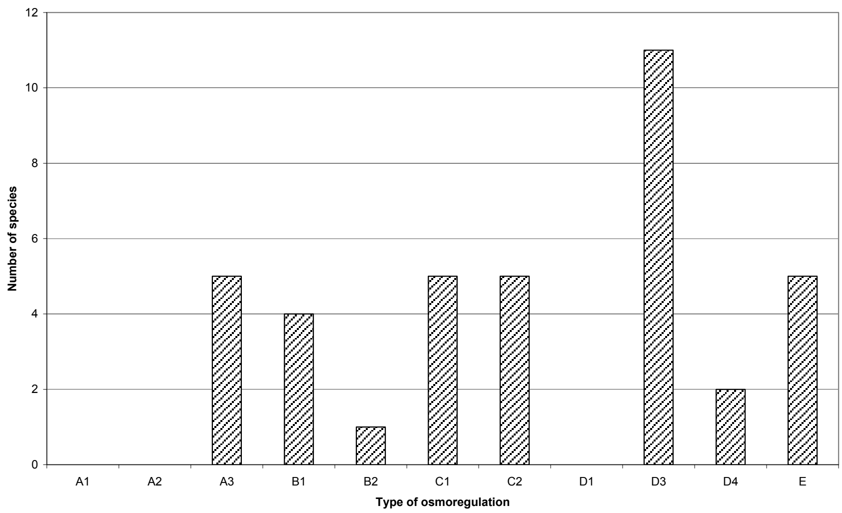

Figure 8. Number of different types of osmoregulation in alien fishes and free-living invertebrates in the Aral Sea.

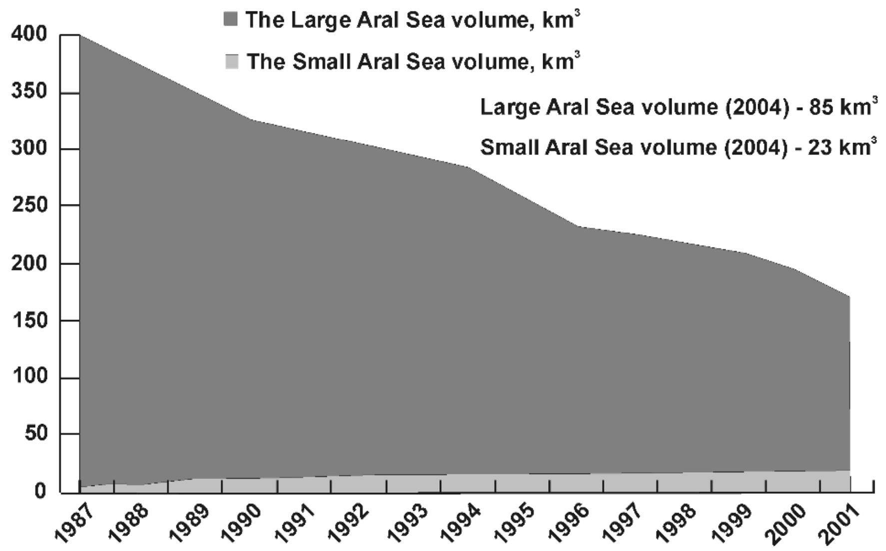

Figure 9. Changes in the Aral Sea volume.

TABLE 3. Hydrologic and salinity characteristics of the Aral Sea.

Year	Level (m asl)	Area (km^2)	% of 1960 area	Volume (km^3)	% of 1960 volume	Average salinity(g/L)	% 1960 salinity
1960 (whole sea)	53.4	67,499	100	1,089	100	10	100
Large Sea	53.4	61,381	100	1,007	100	10	100
Small Sea	53.4	6,118	100	82	100	10	100
1971 (whole sea)	51.1	60,200	89	925	85	10	100
1976 (whole sea)	48.3	55,700	83	763	70	14	140
1989 (whole sea)		39,734	59	365	33		
Large Sea	39.32	36,307	60	341	34	30	300
Small Sea	40.2	2,804	46	23	28	30	300
2007 (whole sea)		13,958	21	102	9		
Large Sea	29.4	10,700	17	75	8	East >100 West 100	>1,000 1,000
Small Sea	42.0	3,258	53	27	33	12?	120
2025 (whole sea)		9,058	14	68	6		
Large Sea[a]	21–28	6,400	10	41	4	>100 to 200	>1,000 to >2,000
Small Sea	42.0	3,258	53	27	33	5?	100

[a]The sea will consist of a western and eastern part with the west basin at 21 m with and the east at 28.3.

Sources: Compiled by P. Micklin from Asarin and Bortnik, 1987 and Bortnik and Chistyaevaya, 1990, Table 8.4, p. 72; Uzglavgidromet, 1994–2003; Water balance models, 1990–2006; Final Report, 2004; Ptichnikov, 2000, 2002; and Expedition, 2005 and 2007.

The zooplankton of the Aral Sea just after its separation (1989) under average salinity about 30 g/L was composed of the following invertebrates: Rotatoria – *Synchaeta vorax*, *S. cecilia*, *S. gyrina*; Cladocera – *Podonevadne camptonyx*, *Evadne anonyx*; Copepoda – *Calanipeda aquaedulcis*, *Halicyclops rotundipes aralensis*; larvae of Bivalvia – In zoobenthos there were Bivalvia – *Abra ovata*, *Cerastoderma isthmicum*; Gastropoda – *Caspiohydrobia* spp.; Polychaeta – *Nereis diversicolor*; Ostracoda – *Cyprideis torosa*; Decapoda – *Palaemon elegans*, *Rhithropanopeus harrisii tridentatus*. Fishes were represented by *Pungitius platygaster*, *Clupea harengus membras*, *Platichthys flesus*, *Atherina boyeri caspia*, *Knipowitschia caucasicus*, *Neogobius fluviatilis*, *N. melanostomus*, *N. syrman*, *N. kessleri*, *Proterorchinus marmoratus*.

2. Conservation and rehabilitation of Aral Sea and its ecosystems

There are four main ways of conservation and rehabilitation of Aral Sea and its ecosystems that were first discussed in Geneva (September 1992 – UNEP meeting):

1. Conservation and rehabilitation of Small Aral
2. Conservation and rehabilitation of Large Aral
3. Conservation and rehabilitation of delta and deltaic water bodies of Syr Darya
4. Conservation and rehabilitation of delta and deltaic water bodies of Amu Darya

Another option would be to give more water to the Eastern Large Aral from Small Aral via Berg Strait and from Amu Darya river via Ak Darya river bed. Level of Western Large Aral Sea might be maintainable using ground water flow from Amu Darya delta and Ustjurt plateau. Realization of this project will help biodiversity conservation.

2.1. WAY 1. CONSERVATION AND REHABILITATION OF SMALL ARAL AND ITS ECOSYSTEMS

Discharge of water from Small Aral occurs primarily in the spring-early summer high flow period on Syr Darya. Since August 2005 outflow has been controlled by a discharge structure (gates) in the dike (Figure 10).

The dike in Berg Strait is preserving the Small (Northern) Aral and rehabilitating its biodiversity. The old dike was built by our proposal in August 1992 (Aladin et al., 1995). It existed, with periodic partial breaches,

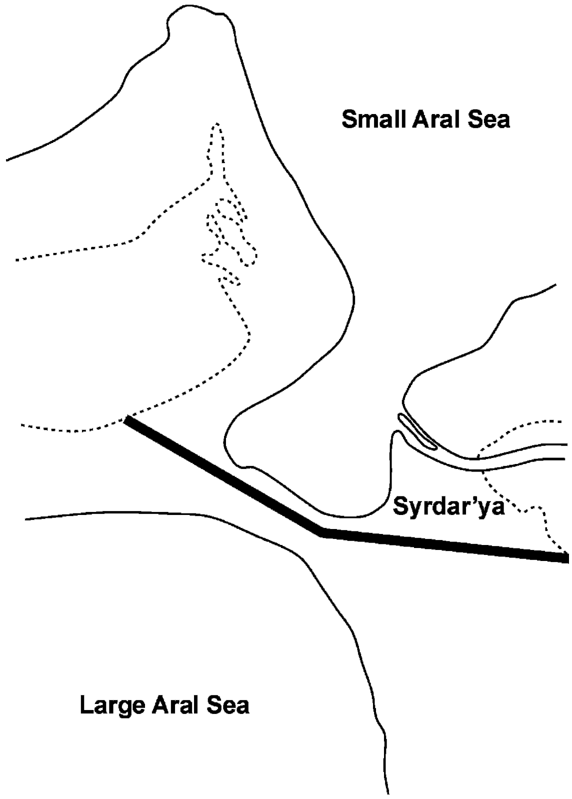

Figure 10. Dike in Berg Strait (by: Aladin et al., 1995).

until April 1999, when after the water level rose to +43.5 m, a catastrophic breach occurred that destroyed the dike. The number of free-living animals increased. Even such a short period allowed partial rehabilitation of biodiversity in Small Aral.

Since separation of the Small Aral Sea from Large Aral at the end of the 1980s, the number of free-living animals increased because salinity in this lake was cut nearly in half and in 2005 reached about 17 g/L. At that time, the Small Aral's area was 2,804 km^2 (47% from 1960), volume 23 km^3 (28% from 1960), and level +40.4 m asl.

Our survey in September 2007 showed the following number of species: Fishes – 12; Rotatoria – 3; Cladocera – 2; Copepoda – 2; Ostracoda – 2; Decapoda – 2; Bivalvia – 2; Gastropoda – >1; Polychaeta – 1. Total: >27.

Zoobenthos of the Small Aral Sea today consist of the following: Bivalvia – *Abra ovata*, *Cerastoderma isthmicum*; Gastropoda – *Caspio-hydrobia* spp.; Polychaeta – *Nereis diversicolor*; Ostracoda – *Cyprideis torosa*, *Eucypris inflata*; Decapoda – *Palaemon elegans*; Insecta: Chironomidae larvae. Fishes of the Small Aral: *Clupea harengus membras*, *Platichthys flesus*, *Atherina boyeri caspia*, *Knipowitschia caucasicus*, *Neogobius fluviatilis*, *N. melanostomus*, *N. syrman*, *N. kessleri*, *Pungitius platygaster*, *Proterorchinus marmoratus*, *Ctenopharyngodon idella*, *Sander lucioperca*. When a dike in the Berg Strait was built in 1992, fishing on the Small Aral was recommenced. According to reports of fishermen in 2004 silver carp (*Ctenopharyngodon idella*) reappeared in Small Aral.

The Russian company "Zarubezhvodstroy" built the new dike in the Berg Strait. It was completed in autumn 2005. In spring 2006 the level of Small Aral reached the design level of 42 m, well ahead of schedule. The Small Aral area in 2007 is about 3,258 km^2, with a volume of 27 km^3.

2.2. WAY 2. CONSERVATION AND REHABILITATION OF THE LARGE ARAL AND ITS ECOSYSTEMS

Since the Aral Sea divided into two lakes at the end of the 1980s, the level of Large Aral Sea has steadily declined. Since the beginning of 2003, when the level in the Large Aral Sea dropped by 23 m and reached about +30 m, the Large Aral Sea has been practically divided into the Eastern Large and Western Large Aral and Tschebas Bay. Salinity in the Western part in September 2007 was 100 g/L; it no doubt is considerably higher in Tschebas Bay and the Eastern Large Aral where it may reach 150–160 g/L.

In both the eastern and western Large Aral salinity has increased so much that most inhabitants are gone. At the end of the twentieth century brine shrimp *Artemia salina* (*A. parthenogenetica*) appeared in the Large Aral Sea. Industrial harvesting by the international company INVE Aquaculture is being considered, but in 2005 the company postponed activities until salinity increases to levels more favorable for brine shrimp.

Zooplankton of the Western Large Aral Sea (2007 average salinity around 100 g/L): Infusoria – *Fabraea salina*; Rotatoria – *Brachionus plicatilis*, *Hexarthra fennica*; Branchiopoda – *Artemia salina*. Possibly could be found Cladocera – *Moina mongolica* and Copepoda – *Halicyclops rotundipes aralensis*. Zoobenthos: Infusoria – *Frontonia* sp.; Turbellaria – *Mecynostomum agile*; Polychaeta – *Nereis diversicolor*; Ostracoda – *Cyprideis torosa*, *Eucypris inflata*; also there is some possibility that Gastropoda – *Caspiohydrobia* spp. and Bivalvia – *Abra ovata* could still survive. In Tschebas Bay zooplankton and zoobenthos resembles those of the Western Large Aral Sea.

It appears that by 2005 all fishes of Western Large Aral Sea had disappeared. Nevertheless there is a chance that in some places, where salinity is lower due to inflow of underground waters, some very salinity tolerant fish species still could survive: *Pungitius platygaster*, *Platichthys flesus*, *Atherina boyeri caspia*, *Neogobius melanostomus*. There is suspect oral information that in Tschebas bay flounder (*Platichthys flesus*) was observed in water with salinity 80–90 g/L. Also there is unofficial information that in the remnants of the strait between Small and Eastern Large Aral *Atherina boyeri caspia* was found in water with salinity 60–80 g/L.

Only a few free-living invertebrates could survive such high salinity conditions: Infusoria – 2; Rotatoria – 3; Cladocera – 2; Copepoda – 2; Ostracoda – 2; Branchiopoda – 1; Decapoda – 2; Bivalvia – 2; Gastropoda – >2; Polychaeta – 1 for a possible total of fewer than 18.

Zooplankton and zoobenthos of the Eastern Aral Sea (2007 average salinity probably 150–160 g/L): Zooplankton – only *Artemia salina*; zoobenthos – no live macro- and mezo-Metazoa are found. Fishes are not found in the Eastern Large Aral; they are completely gone.

In 2005 a special water discharge facility (dike, water way and water discharge gates) was constructed in order to supply the Eastern depression of Large Aral with Amu Darya water from the Mezhdurechensky reservoir via the Ak Darya river bed. Unfortunately the completed spillway and water gates failed and were destroyed in October 2005 when the coffer dam holding back the water of the reservoir was removed. The cause was probably poor engineering design or construction. Now this complex is under restoration.

It may be desirable to provide more water to the Eastern Large Aral from Small Aral via the Berg Strait dike and water discharge from Mezhdurechensky reservoir via Ak Darya river bed. Western Large Aral Sea could, perhaps, maintain its level using ground water flow from Amu Darya delta and Ustjurt plateau. Realization of this project will help protect biodiversity of salt tolerant species of hydrobionts.

2.3. WAY 3. CONSERVATION AND REHABILITATION OF DELTA AND DELTAIC WATER BODIES OF SYR DARYA

After the collapse of the USSR, discharge of Syr Darya slightly increased and reached about 5 km^3 per year. After making a first dike in the Berg Strait in summer 1992 some other rehabilitation projects were initiated. Syr Darya delta shifted slightly northwards and some fresh water reservoirs were built. Along lower Syr Darya near the Small Aral several fresh water lakes have been rehabilitated: Tuschibas, Kamyslybas, Zhalanashkol, Karasholan, etc. These small projects allow the restoration of freshwater fisheries, hunting, and trapping. Fish farms were also renewed and more young fish are released to the local water bodies. Fish farms are also planned for use in reintroduction of sturgeon to the Small Aral.

2.4. WAY 4. CONSERVATION AND REHABILITATION OF DELTA AND DELTAIC WATER BODIES OF AMU DARYA

Uzbekistan branch of IFAS in cooperation with other national institutions prepared a plan of Amu Darya delta rehabilitation. In the lower reaches of the Amu Darya several freshwater and brackish water reservoirs and lakes were established. One of the most successful projects is Sudochie Lake. Sudochie Lake has been filled and via underground flow is giving some water to the Western Large Aral Sea. Reeds, aquatic birds and hydrobionts are almost recovered in Sudochie Lake. Other former Aral Sea bays have or could be rehabilitated, including Sarbas, Muynak, Adjibay and Zhiltyrbas. Fisheries and hunting activities have recovered in the areas that have been rehabilitated.

3. Some evidences of Medieval desiccation of the Aral Sea

As the Aral dried (Figures 11–15), remnants of saxauls were found on its former bottom. Some stumps were also found under water close to the modern shoreline. Radiocarbon analysis dated these to Medieval times. For more paleo-environmental reconstruction of Medieval desiccation special corings in the Aral Sea were made under the CLIMAN project (INTAS).

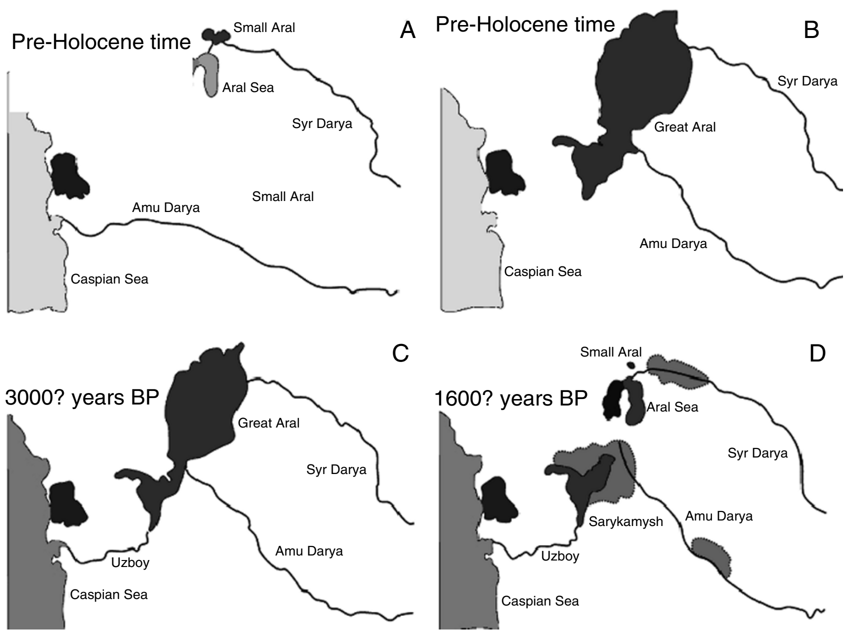

Figure 11. Aral Sea: from 9,000 to 1,600 years BP (by: Aladin and Plotnikov, 1995).

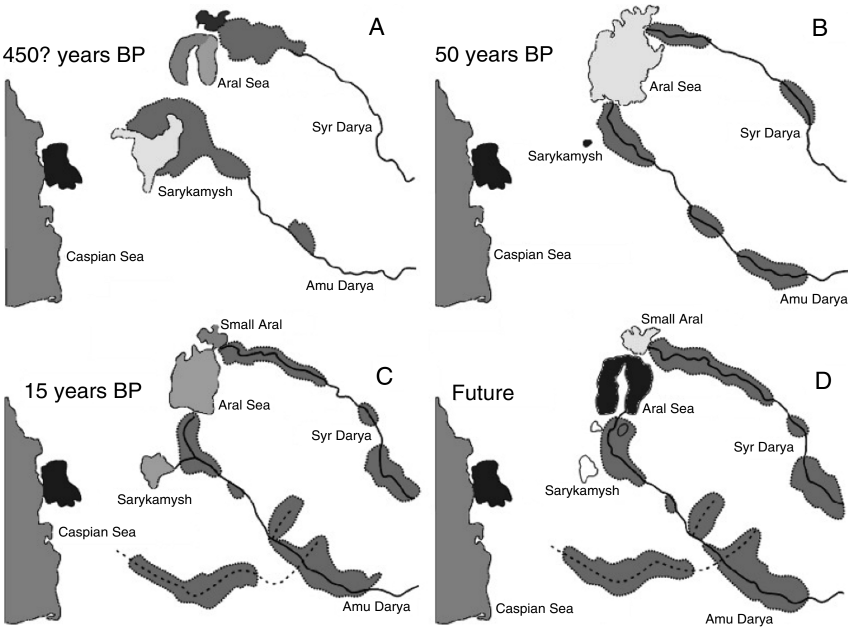

Figure 12. Aral Sea: from 450 years BP to present and in the future (by: Aladin and Plotnikov, 1995).

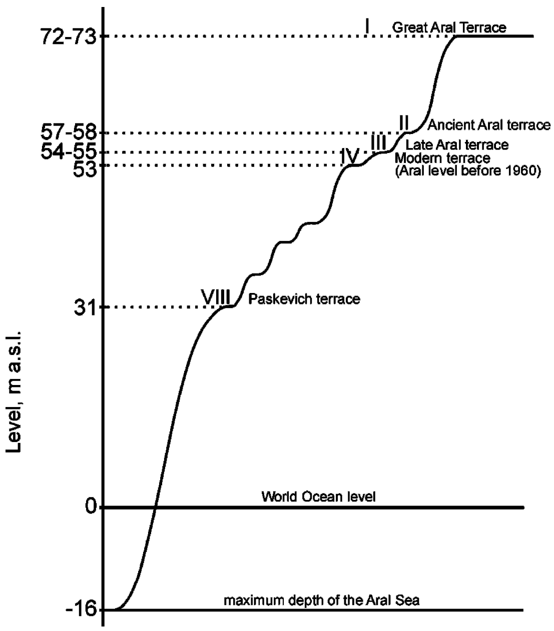

Figure 13. Main Aral Sea terraces (by: Aladin and Plotnikov, 1995).

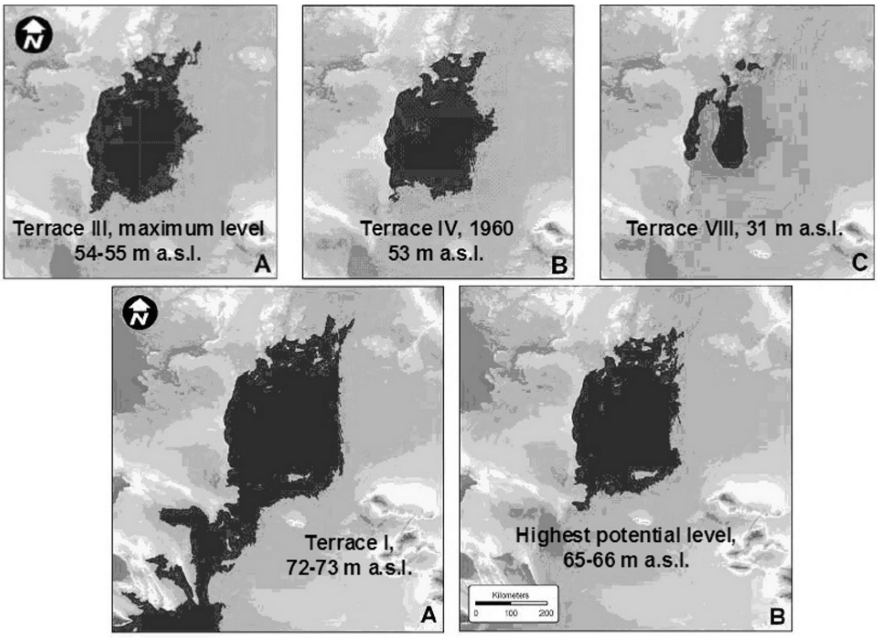

Figure 14. Surface areas of the Aral Sea at different levels (From: C. Reinhardt, 2007).

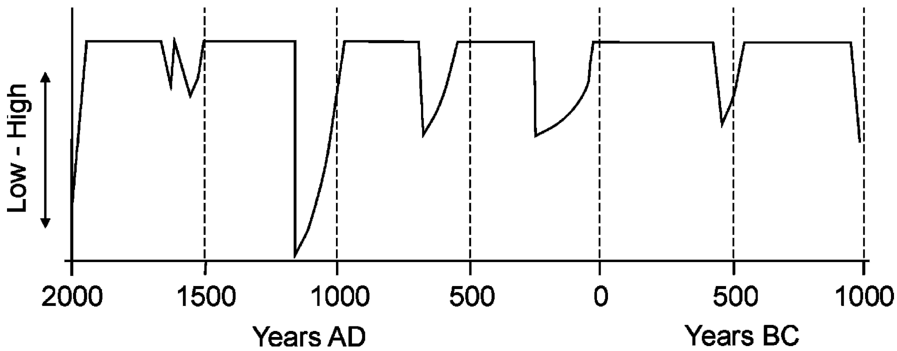

Figure 15. Aral Sea water level change during last 3,000 years (based on archeological data). Boomer et al., 2008 [Chapter by Boroffka].

At the end of twentieth century, Kazakh hunters found ruins of a Medieval mausoleum (Kerdery) on the dried bottom. In 1960, the area was under about 20 m of water. Bones of *Homo sapiens* and domestic animals, millstones, elements of ceramics, and other artifacts were found near the mausoleum. All these findings were studied by an international team of archeologists also under the CLIMAN project (Boroffka et al., 2005).

Recently remnants of Medieval river beds on the former Aral Sea bottom were also detected on satellite images. Preliminary investigations on this matter were made by D. Piriulin (personal communication, 2007).

4. Alternative 2nd phase of the small Aral rehabilitation project

In our opinion, the future of the Aral Sea is connected with oil and gas extraction. Oil and gas drilling rigs are now wide spread on the former Aral Sea bottom. A gas condensate plant was built not far from Muynak. Local decision-makers even permanently closed the channel that formally gave water to Muynak reservoir. The gate was closed in order to decrease the groundwater level in the area. A high water table level promotes softening of the ground that endangers drill towers, possibly causing them to fall over or start to lean.

The authors would like to note that citizens of Kazakhstan like to call Small (Northern) Aral Sea “Kazaral” that means “Kazakh Aral”. People in Uzbekistan also sometimes instead of Large (Southern) Aral Sea like to use

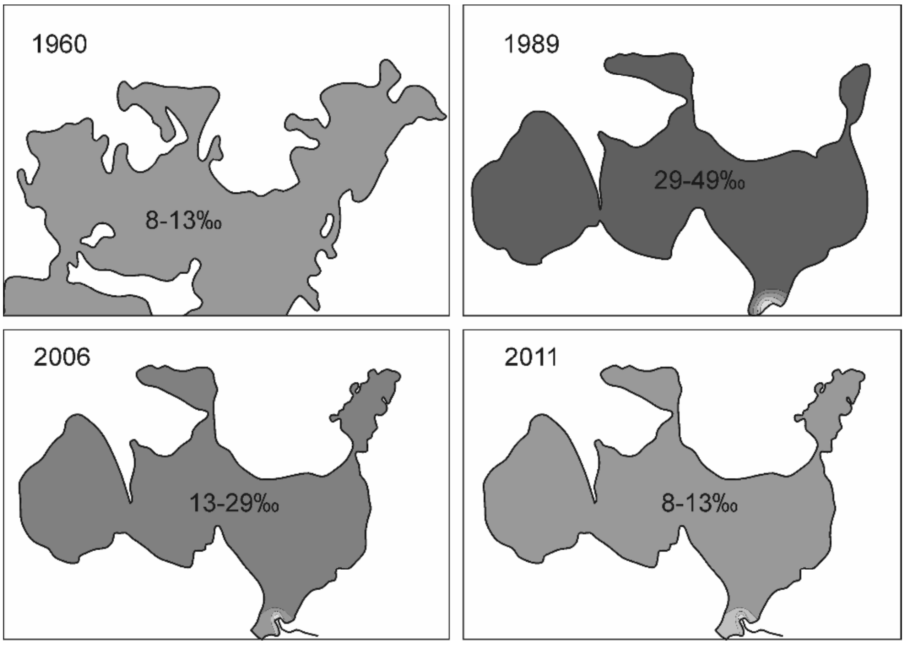

Figure 16. Dike in the Berg Strait funded by World Bank and Kazakhstan government allowed to improve brackish water environment of Small (Northern) Aral Sea.

name “Uzaral” that means “Uzbek Aral”. We believe that on future maps will be four main water bodies in what was formerly the Aral Sea: Kazaral, Western Uzaral, Eastern Uzaral, and remnant of Tshebas bay.

The dike in the Berg Strait allowed the level in the Small (Northern) Aral Sea to increase to +42 m asl. Present average salinity in Small (Northern) Aral Sea is about 10 g/L. For further improvement of this situation improvements in irrigation efficiency are needed to improve water balance. It is possible to make the present dike a bit higher and raise the level up to +45 m asl. This will allow enlarging the volume and area of Small (Northern) Aral Sea (Figure 16).

Another possible variant of the second phase of the “Kazaral” rehabilitation project is shown in Figure 17. It would involve construction of a new dike at the mouth of the Saryshaganak Gulf to raise the level of it to +46 or 47 m. Part of the flow of the Syr Darya would be diverted northward to fill the reservoir.

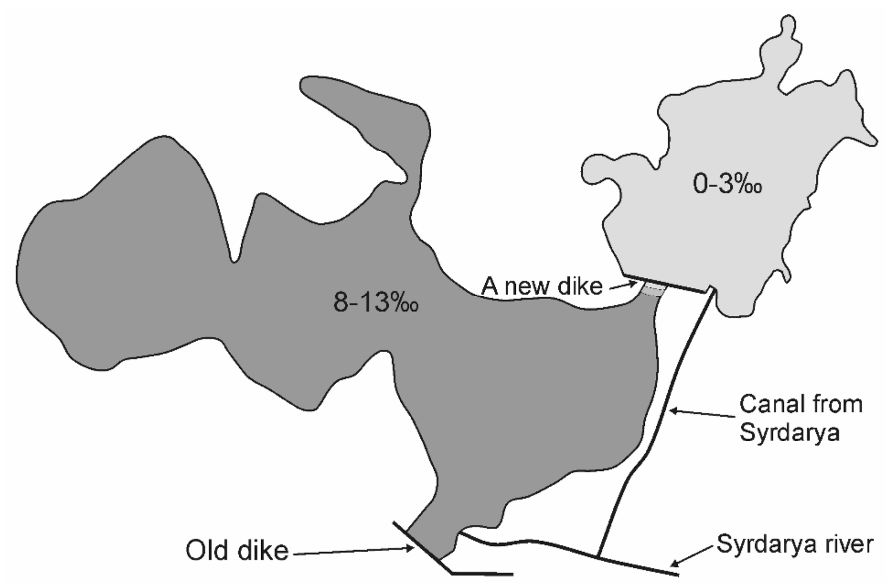

Figure 17. A variant of the second phase of Small Aral Sea rehabilitation project.

The second phase of the project will allow further improvement of the health of the local people, decreased unemployment and increased living standards, as well as income to local families. The local economy also will be improved (fishery, shipping, etc.). Local microclimate around Small (Northern) Aral Sea will be much better than now.

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WATER SCARCITY IN THE ARAL SEA DRAINAGE BASIN: CONTRIBUTIONS OF AGRICULTURAL IRRIGATION AND A CHANGING CLIMATE

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Abstract. Changed ambient conditions in the Aral Sea Drainage Basin (ASDB) in Central Asia have led to drastically decreased river discharges into the Aral Sea during the twentieth century. This decrease has in turn led to the still ongoing Aral Sea desiccation and to particularly adverse environmental effects, in terms of both affected number of people and degree of environmental degradation in the ASDB. We have used a distributed basin-scale hydrological balance modeling approach for estimating the relative influences of agricultural irrigation and climate change, respectively, on observed decreases of river discharges in the ASDB. Results show that water losses through evapotranspiration increased as a result of higher temperatures in the basin after 1950. However, these increases in evapotranspiration loss due to rising temperatures alone are smaller than the water gains caused by increased precipitation in the ASDB over the same time period. Climatic changes can therefore not at all have contributed to the observed drying of the rivers in the basin, at least not so far. By contrast, the evapotranspiration loss increases from the expanded agricultural irrigation in the area can fully explain the decreased river discharges and the present water scarcity in the ASDB. We further show that the largest increase (1.85°C) in seasonal average temperature in the basin has occurred in the winter, whereas the smallest increase (0.69°C) has occurred in the summer. This result is consistent with a surface temperature cooling effect of intense irrigation in the summer, which should have increased since the 1950s due to the evapotranspiration increase implied by the major irrigation expansion in the ASDB.

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Keywords: Aral Sea Drainage Basin, hydrology, water scarcity, agriculture, land use, irrigation, runoff, climate change, modelling

1. Introduction and objectives

Development of sustainable agricultural practices in arid, water-stressed regions is associated with considerable difficulties. Excessive irrigation schemes have caused adverse environmental effects worldwide. A particularly severe example, in terms of both affected number of people and degree of environmental degradation, is provided by the on-going and deepening environmental, health and socio-economic crisis in the Aral Sea Drainage Basin (ASDB) in Central Asia. Key problems include water shortage due to salinization and pollution of water resources; food shortage due to smaller crop yield from degraded soils; health problems due to pollution of water, food and the environment; and economic decline as an aggregate result of the above problems. This deeply influences Central Asia and the socio-economic state of its population.

Figure 1 shows the location and boundary (water divide; thick, solid line) of the vast (1,874,000 km^2) Aral Sea Drainage Basin, which is shared by Kazakhstan, Turkmenistan, Uzbekistan, Afghanistan, Kyrgyzstan, and Tajikistan. The two principal rivers, the Amu Darya and the Syr Darya, originate in the mountains of Tajikistan and Kyrgyzstan, respectively. During the twentieth century, the basin has undergone an enormous irrigation expansion. At the end of the century, in the year 2000, approximately 8 million hectares of land were irrigated (shaded areas in Figure 1). Through the largest canal, the Karakum Canal, about 10 km^3 of water per year is diverted to areas located outside of the ASDB.

The changed ambient conditions in the ASDB during the twentieth century have led to a drastically decreased total river discharge into the Aral Sea, from a pre-1950 value of about 60 km^3 per year or more (sum of Amu Darya and Syr Darya discharges), down to 10 km^3 per year, or less, in recent times (see, e.g., Benduhn and Renard, 2004). As a consequence, the Aral Sea has lost 90% of its relatively stable pre-1950 volume. In contrast to the river discharge, the total groundwater discharge into the Aral Sea has most likely not undergone any significant changes during the past century, but is in relative terms currently much more important for the freshwater input to the Aral Sea than under pre-1950 conditions (Jarsjö and Destouni, 2004; Alekseeva et al., 2007). However, the shallow groundwater in certain regions, such as the Amu Darya river delta to the south of the Aral Sea,

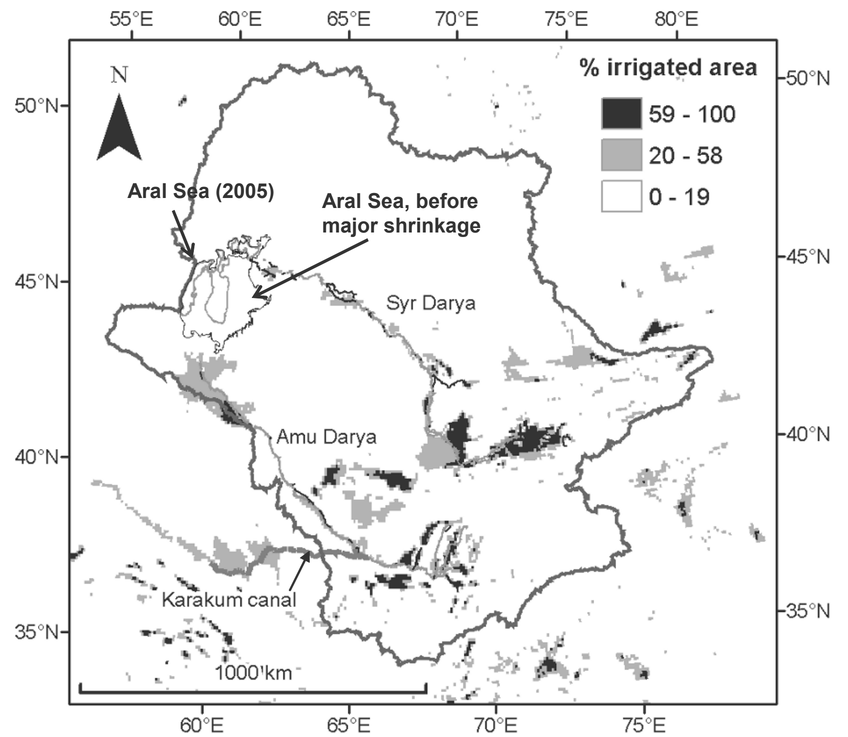

Figure 1. The Aral Sea Drainage Basin (ASDB, delimited by the thick solid line, based on the basin delineation by Shibuo et al. (2007)) with the Aral Sea and its two principal rivers, the Amu Darya and Syr Darya, and location of irrigated areas (shaded).

is highly saline (e.g., Johansson et al., 2007). Furthermore, in regions characterized by flat topography, such as the Amu Darya delta, saline Aral Sea water still remains in the shallow aquifers below the now exposed Aral Sea bottom (Shibuo et al., 2006).

In addition to changes in land-use caused by the mega-scale water diversions described above, considerable climatic change has been observed within the ASDB during the twentieth century. This climatic change may also have affected hydrology and freshwater availability within the ASDB. In particular, changes during the growing season, i.e., spring to autumn, may influence irrigated agriculture. This study uses recent results of Shibuo et al. (2007) as a basis for investigating the relative contributions of water diversions and land use changes on the one hand, and climatic changes on the other hand, to the present water scarcity in the Aral Sea vicinity. In particular, we investigate if and how climatic change effects on hydrology and freshwater resources may differ seasonally.

2. Method and considered scenarios

We analysed changes in evapotranspiration ET and resulting water discharges into the Aral Sea in the ASDB using a distributed basin-scale hydrological balance model, in which the locally created runoff (i.e., precipitation P minus ET) is estimated using long term averages (considering time periods between 20 and 50 years) of precipitation and temperature T as driving values (see Shibuo et al., 2007 and Jarsjö et al., 2008, for details). Spatially distributed P and T data for the whole ASDB were obtained from the Climate Research Unit (CRU) TS 2.1 database. We used PCRaster/ Polflow model routines (De Wit, 2001; Jarsjö et al., 2008; Lindgren et al., 2007) for downstream routing of the runoff through the flow network, using a model discretization of 3,000 times 3,000 grid cells.

In the first scenario, we used the model to reproduce ET and water discharges in the ASDB in the pre-1950 period, i.e., at a time when the discharges into the Aral Sea were not yet considerably affected by irrigation and/or climatic changes. In a second, hypothetical scenario, we used the developed hydrological model to investigate the possible influence of only the observed climate change on water discharges. This was done by updating the pre-1950 model with temperature and precipitation data from the more recent 1983–2002 period, without considering the effects of the large water diversions and irrigation changes of the twentieth century. Finally, in the third scenario, we considered both the observed climate change and the known twentieth century water diversions and irrigation changes, thereby reproducing the actual current conditions of the ASDB. Further details on the modelling and scenario analysis are given in Shibuo et al. (2007).

3. Temperature – overall and seasonal trends

Figure 2 shows the observed annual average temperature within the ASDB between 1901 and 2002. The observed temperature is on average about 1.1°C higher during the recent period 1983–2002 than during 1901–1950. In order to investigate possible seasonal differences, we analysed also the temperature data separately for the spring (March, April and May), summer (June, July and August), autumn (September, October and November) and winter (December, January and February) seasons.

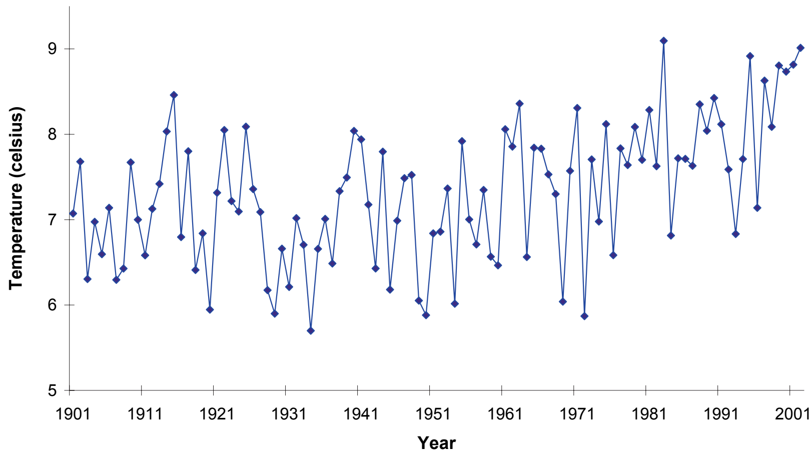

Figure 2. Temporal trends in temperature data within the ASDB (based on the basin delineation by Shibuo et al. (2007; see also Figure 1) and temperature data from Mitchell and Jones (2005)).

We found that the temperature increase was largest for the winter season (1.85°C) and smallest for the summer season (0.69°C). The increases during the spring and autumn seasons were 1.07°C and 0.81°C, respectively. Figure 3 shows further that the seasonal temperature changes are not uniformly distributed over the ASDB. For instance, considering the spring season with its average temperature increase of about 1°C for the whole ASDB, Figure 3a shows that the north-western region of the basin (in the Aral Sea vicinity) has experienced even higher temperature increases of up to 2°C. By contrast, in the mountain areas in the south-eastern region of the basin, the temperature increase is smaller. A similar spatial trend with even greater contrasts is observed in winter (Figure 3d), whereas the trend is considerably different in autumn (Figure 3c) with the smallest changes then occurring in the Aral Sea vicinity and in the vicinity of the Amu Darya headwaters. In summer (Figure 3b), the increase in temperature is both relatively small and relatively uniform over the whole basin.

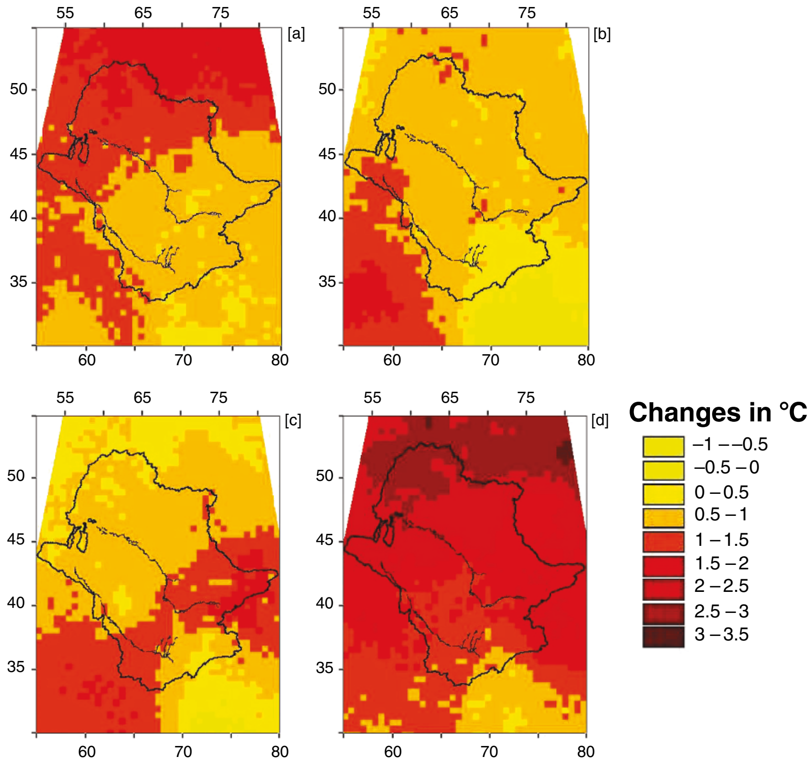

Figure 3. Spatial distribution of average temperature change from the 1901–1950 period to the 1983–2002 period for (a) Spring (March, April, May), (b) Summer (June, July, August), (c) Autumn (September, October, November) and (d) Winter (December, January, February) seasons.

4. Precipitation – overall and seasonal trends

Figure 4 shows the temporal trends in annual average precipitation between 1901 and 2002. The recent time period (1983–2002) exhibits an increase in annual precipitation of about 15 mm on average compared to the 1901–1950 conditions. This precipitation increase (increased water input) is counterbalanced by an increased ET (i.e., increased water loss); the net total water balance effect is discussed further in the section below. The seasonal analysis reveals increases of 3.8 mm (5%), 3.0 mm (4%), 2.2 mm (5%) and 6.0 mm (9%) in precipitation for spring, summer, autumn and winter respectively. Hence, a relatively large fraction of the additional annual precipitation falls during winter, or 6 mm out of the total annual 15 mm addition.

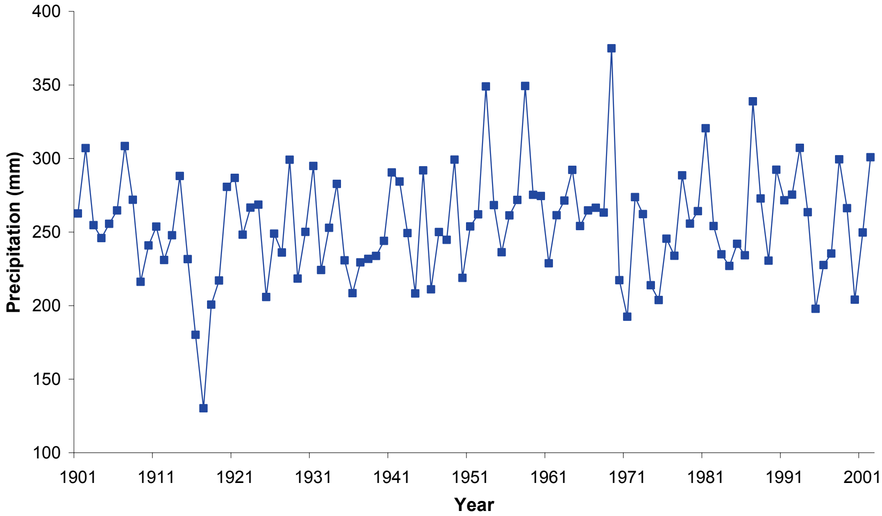

Figure 4. Temporal trends in precipitation data within the ASDB (based on the basin delineation by Shibuo et al. (2007; see also Figure 1) and precipitation data from Mitchell and Jones (2005)).

The spatial distribution of seasonal precipitation change (Figure 5) from the pre-1950 period to the 1983–2002 period exhibits a more or less general trend of relatively high precipitation increases somewhere in the south-eastern part of the ASDB. The highest increase of about 125 mm is during summer at and around the southern to south-eastern boundary of the ASDB. Within the basin, relatively large increases in precipitation occurred near the mountain area in the south-eastern part of the basin during winter. In all seasons, the highest precipitation increases occur thus somewhere within the south-eastern part of the basin, in the vicinity of extensive irrigation areas (Figure 1).

5. Causes of the water scarcity

The hydrological balance modelling results of Shibuo et al. (2007) show that the water losses by evapotranspiration (ET) increased after 1950 mainly due to the irrigation changes, rather than due to the temperature changes, within the ASDB. The ET loss increases due to temperature increases alone were found to be smaller than the water gains due to the also increased precipitation over the ASDB since 1950. This means that the net hydrological effect of only the climatic changes within the ASDB would be slightly increased, rather than the observed decreased river runoff. Climate

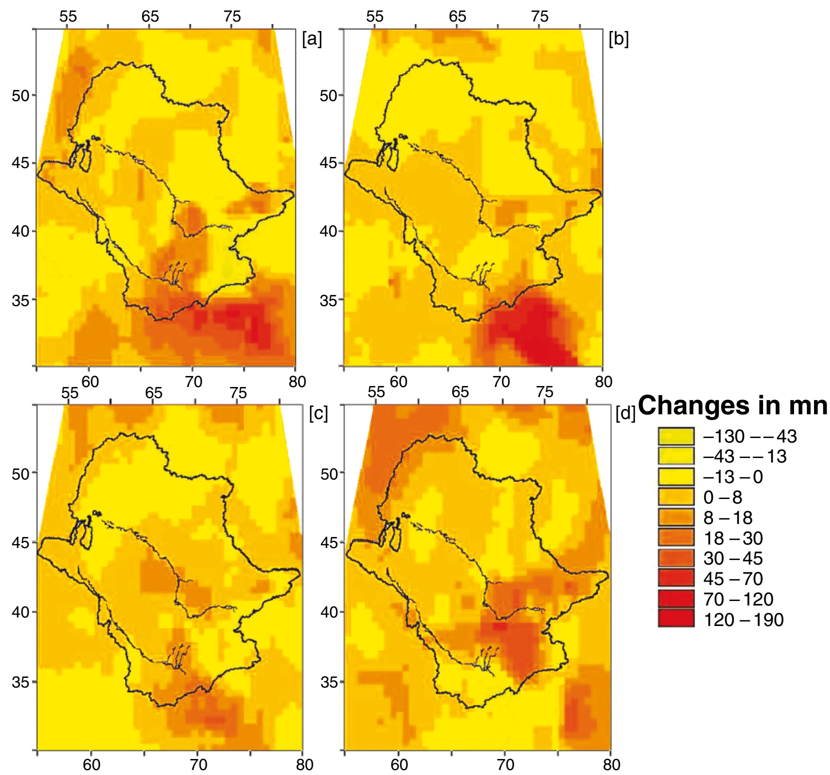

Figure 5. Spatial distribution of precipitation change from the 1901–1950 period to the 1983–2002 period for (a) Spring (March, April, May), (b) Summer (June, July, August), (c) Autumn (September, October, November) and (d) Winter (December, January, February) season.

change can therefore not at all have contributed to the dramatic drying of the rivers that has led to the present water scarcity in the basin, at least not so far. The increased ET flux from the considerably expanded irrigated agricultural fields, however, can fully explain the decreased river discharges and the present water scarcity in the basin.

In this paper, we have specifically investigated the seasonal trends of climatic changes in the ASDB. Our results show that the average temperature increase in the ASDB of 1.1°C since the 1950s is unevenly distributed over the four seasons. The largest increase of 1.85°C occurs during winter, whereas the smallest increase of 0.69°C occurs during summer. This is consistent with a surface temperature cooling effect from vastly increased ET caused by intense irrigation during the summer. This cooling effect should have increased since the 1950s due to the irrigation expansion. Furthermore, the cooling effect would be predominant during the summer season (counteracting possible temperature increases in that season for reasons such as global climate change) and negligible during the winter season (allowing full development of regional temperature increases in that season due to, e.g., global climate change).

The present results also show that in all seasons the precipitation increases within the ASDB are greatest in the south-eastern part of the basin, where the irrigated areas are located. This season-consistent result supports the interpretation made by Shibuo et al. (2007) that regional irrigation practices may considerably affect regional climatic conditions. In order to obtain more conclusive results on seasonal irrigation effects on both temperature and precipitation, however, one would need to conduct coupled hydro-meteorological analyses, which should be an interesting direction of future research.

Acknowledgements

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USE OF BIOSENSORS TO DETECT AND MONITOR CHEMICALS COMMONLY USED IN AGRICULTURE AND TERRORIST WEAPONS WITH THE GOAL OF PREVENTING DANGEROUS ENVIRONMENTAL CONSEQUENCES

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Abstract. In this chapter, based on literature review and our own data analysis, biosensors were developed based on biosensor principles. Specifically, biosensors intended for the determination of total toxicity, gene toxicity, and for detecting groups of toxic elements and individual toxins are described in detail. The following individual toxins were singled out using biosensors: mycotoxins, phenol substances, surfactants, and cyanides, as well as formaldehyde and volatile carbonyls. These sensors can be used in environmental assessments to detect and monitor chemicals commonly used agriculture management, and even terrorist weapons.

Keywords: Total toxicity, gene toxicity, toxic element groups, individual toxins, biosensors

1. Introduction

Some organic chemical substances (OChS) or their mixtures contain numerous collections of compounds, the dispersion of which into the environment demands constant control, since as a rule they are toxic, stable, and prone to bioaccumulation and long term transfer into the atmosphere (Vallack et al., 1998). Therefore these OChS may affect living organisms far from the places they are released.

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The global dispersion of OChS is evinced by their discovery in the Arctic, where they are never produced and where their concentration has reached a level which threatens wildlife and humans (Barrie et al., 1992; Mulvad et al., 1996). According to ecological and manufacturing classifications, OChS may be divided into pesticides, products of industry (polychlorinated biphenyls and hexachlorbenzenes), and concomitant products (dioxins, furans and polycyclic hydrocarbons) (Vallack et al., 1998).

There are special regulations regarding the total amount of surfactants and mycotoxins each country can produce. The surfactant production in the USA alone reached ≈5 × 109 t in 1997 (Morse, 1999). In spite of the fact that the use of biodegradable surfactants has been mandated in all countries, these chemicals never completely mineralize and they accumulate gradually in natural water sources (Council Directive 82/242, 1982). Acute effects of OChS are well known and the cases of their release in large concentrations and associated disasters have been reported widely (Brouwer et al., 1998; Eriksson, 1997). Chronic sub-lethal effects of OChS are associated with worsening of reproductive performance, immune toxicity, and damage to skin, neural and endocrine systems (Birnbaum, 1995; Colborn, 1991; Mocarelli et al., 1996). Once released into environment, OChS may be absorbed by phytoplankton, filter organisms and vegetables (Thomann et al., 1992; Kipopoulou et al., 1999; Eriksson et al., 1989) that can reach the human food chain.

Mycotoxins also belong to OChS. These substances include more than 300 individual toxins produced by different fungi (Mirocha et al., 1983). T2, aflatoxins, searelenone, patulin and others are of great interest, since they are widespread and contain a high level of toxicity. T2 mycotoxin has a more toxic effect (400 times more toxic) than mustard gas and lewisite. It is well-known that mycotoxin T2 was packed into rockets, bombs, cisterns, some explosive cylinders, and hand-grenades used in Laos and Afghanistan as “yellow rain” (Rosen and Rosen, 1982; Morris and Clifford, 1985). The preparation of this mycotoxin is very simple. Thus, its easy access and high toxicity pose a serious threat, since these toxic elements may be weaponized by bioterrorists. It is necessary to mention that the use of toxins as biological warfare agents by terrorists is more probable than the use of viruses and bacteria, as the latter pose serious danger not only to the targets, but to the executors of terrorist act, too.

Taking into account the global dispersion of OChS and extraordinary dangers which they present for living organisms, the exigency arises to prevent imminent catastrophe. The true imminence of this situation becomes clear when the large scale of production and consumption of OChS is considered.

The most effective ways to prevent catastrophe are to sharply decrease the entry of OChS into the environment and to constantly monitor the presence of these chemicals (Lacorte et al., 2001). The first measure may be achieved in large part through waste water purification; the second can be accomplished in full measure by applying new instrumental analytical devices which are developed on the basis of chemo- and biosensor technology. It is necessary to mention that environmental instrumentation is constantly improving in terms of sensitivity and selectivity, simplicity, speed and cost, as well as ease of operation and portability. The greatest potential option for successful practical implementation of environmental monitoring is believed to be biosensors, the development of which began at the end of the 1950s and beginning of the 1960s. Development of biosensors continues to progress, and today the prospective prototypes are distinguished in both theoretical and practical aspects.

The main purpose of this article is to present some prototypes of biosensors which were developed in the Institute of Biochemistry of the Ukrainian National Academy of Science (UNAS). Special attention is paid to analytical characteristics of biosensors and the role of concrete instrumental devices in an entire monitoring system designed for different environmental object detections.

2. Results and discussion

In the early stages of development of biosensors intended for OChS control, principles gained through traditional microbial biotests were used: transformation of microorganisms and characterization of their vital function. Thus, it was shown that a lot of enzymes (dehydrogenases, phosphatases, urease, glucose-6-phosphatase and others) are very sensitive to some OChS.

A number of biotests were carried out based on: (a) characterization of growth and death of bacterial cultures (for example: *Pseudomonas fluorescens* P-17, *Spirrilum sp*. Strain NOX); (b) estimation of respiration level according to oxygen consumption in aerobes and increase of atmospheric pressure in anaerobes; and (c) determination of the ability of *Eschericha coli* to produce labeled CO_2 in the presence of ^{14}C-glucose. The measurement of bioluminescence of microorganisms, in particular *Vibrio fischeri*, was used as well. For registration of all above numerated parameters, different instrumental testing systems were introduced and industrially produced, including Microtox, Lumistox, Mutatox and others (Rosen and Rosen, 1982). Still, to accelerate analysis and to fulfill other practical demands mentioned above, it is necessary to integrate sensitive biological material with a specific physical surface that directly transforms physical-chemical signals generated by this material into electrical signals. These signals are then registered, processed by a very simple electronic device and presented as visible, acoustic, or other information. This is the basis of biosensors. Their classification and general characteristics were described in a number of reviews (Starodub and Starodub, 2000, 2001a, c; Bevza et al., 2002). Below are detailed data about biosensors developed by our group for the control of total toxicity of environmental objects, and determination of groups of toxic elements and some individual toxins.

The foci of our research activities in this field include fundamental research, creation of working prototypes, and technological development of some elements of biosensors. The fundamental aspect includes selection of types of transducers (physical surfaces) and physical-chemical signals for the registration of the interaction of biological molecules with analytes, as well as selection of sensitive biological materials and development of effective methods for the oriented immobilization of this material. The prototypes of biosensors are applied in the area of human and veterinary medicine, ecology and biotechnology. After examination of the biosensor operation in real conditions, some elements of biosensor production are also refined.

The main biological and physical elements used in the development of biosensors, as well as the principles used to register signals generated after interaction of the sensitive biological material with the analyzed substance are shown in Table 1.

TABLE 1. Main components and the principles of signal measurements used in the development of biosensors.

Biological material	Transducers	Principles of generated signal registration
Enzymes	Planar electrodes Ion-sensitive field effect transistors IsFETs)	Electrochemical (potentiometry, amperometry, electro capacity)
Immune components (antibodies or antigens)	Semiconductors structures Fiber optics (optrodes) Porous silicon Thermistors Micro calorimeters	Optical (luminescence, fluorescence: evanescent wave and non-emitting energy transfer, surface plasmon resonance – SPR, total reflection ellipsometry – TIRE) Thermometry
Cells (micro organisms)	Fiber optics (optrodes) Chemiluminometer	Luminescence
Small living organisms (*Daphnia magna*)	Fiber optics (optrodes) Chemiluminometer	Luminescence

To control total toxicity of an environment we used bioluminescent bacteria with optical signal registration and determination of the intensity of *Daphnia* exometabolites using chemiluminescence. Groups of toxic elements are detected by the electrochemical and thermo metrical biosensors, with the sensitive elements being presented by special micro organisms and enzymes. Determination of the concrete toxic elements is achieved using electrochemical and optical biosensors based on the enzyme and immune components as the selective structures on one side and the different types of transducers, including surface plasmon resonance, porous silicon, and electrolyte-insulator structures, on the other side.

2.1. TOTAL TOXICITY

The most often proposed biosensors operate on the basis of micro-organisms, the level of metabolic activity of which may be estimated according to changes in pH, oxygen consumption or CO_2 release, redox potential, and formation of lactate and heat. Devices used for this purpose include IsFETs, light-addressable potentiometric sensors, amperometric electrodes, micro calorimeters and others (Bousse, 1996).

Usually different living organisms (*Crustacea*, fish, algae, fungi, some vegetables and others) are used to control total toxicity of environmental objects. An international standard exists on the basis of the determination of some indices of *Daphnia* immobilization (ISO 6341:1996(E). Unfortunately it is a very routine procedure. Other approaches used in practical applications are based on control of oxygen consumption by microorganisms or determination of their luminescence.

2.1.1. *Method using Daphnia as the sensitive object*

We propose a new approach based on the determination of the chemi-luminescence (ChL) level of live *Daphnia*. The differences in signals before and after introducing *Daphnia* in the solution to be analyzed were registered. In the experiments *Daphnia magna* Straus (*Cladocera*) was used, which was kept in the medium according to International standards (Thomann et al., 1992). In preliminary experiments it was shown that 1–5 *Daphnia's* only are sufficient for experiments (Ivashkevich et al., 2002). The resulting ChL of the medium was registered in the presence of luminol and hydrogen peroxide. Luminol and hydrogen peroxide were added to the medium for the enhancement of this ChL. The optimal concentrations of the above numerated chemicals were preliminarily established in special experiments (Ivashkevich et al., 2002). Stationary, semi-portable and portable devices supplied by optrods, a highly sensitive photomultiplier, or photo resistors were developed for the determination of the intensity of ChL (Figure 1). In dependence on source of toxic substances we have obtained deviations of ChL values from the initial levels, which were in compliance with the intensity of toxic effect.

The standard testing method with immobilization of *Daphnia* was used to compare results. Potassium biochromate was used as the standard chemical solution and its toxicity was checked by the generally accepted method (according to index of *Daphnia* immobilization) using a biosensor based on the determination of level of ChL of the live *Daphnia*. Some obtained results are presented in Figure 2. It was stated that the generally accepted method reveals 0.1 mg/L of potassium biochromate as the minimal level. At the same, time the sensitivity of the proposed biosensor approach

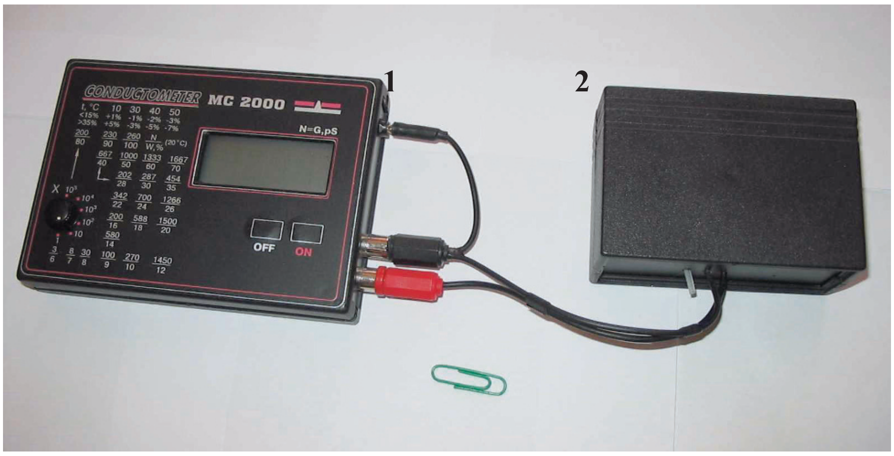


Figure 1. Portable analytical devices for luminescence registration. 1, 2 – electronic block and reactor box, respectively.

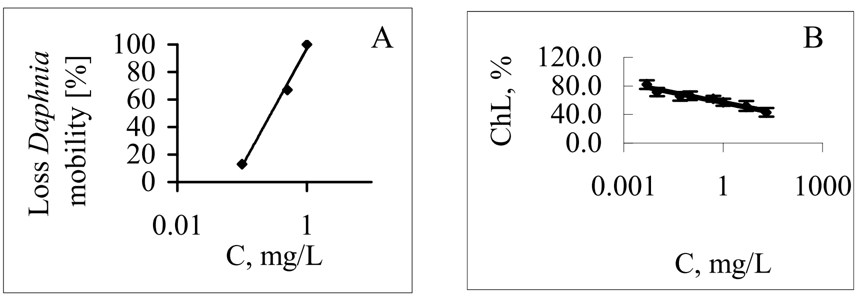


Figure 2. The estimation of biological activity of *Daphnia* (as sensitive structure) after exposure to a solution of potassium bichromate by: generally accepted (A) and biosensor (B) methods.

was almost two orders higher (Gojster et al., 2003). It is necessary to mention that the overall time of analysis varied greatly in both cases (about 24 h and 30 min for the standard accepted and proposed biosensor methods, respectively).

Sensitivity of *Daphnia* to patulin was demonstrated in Pilipenko et al. (2007). Measurements of T2 mycotoxin by the standard accepted method were in the frame of concentration of 0.01–0.1 mg/L. Using the biosensor method, this frame was from 0.001 to 1 mg/L. Moreover the level of sensitivity did not depend on time of *Daphnia* incubation in the solution to be analyzed. As far as patulin, it was possible to determine its quantity using the biosensor method in frame of 0.001–1 mg/L (Figure 3).

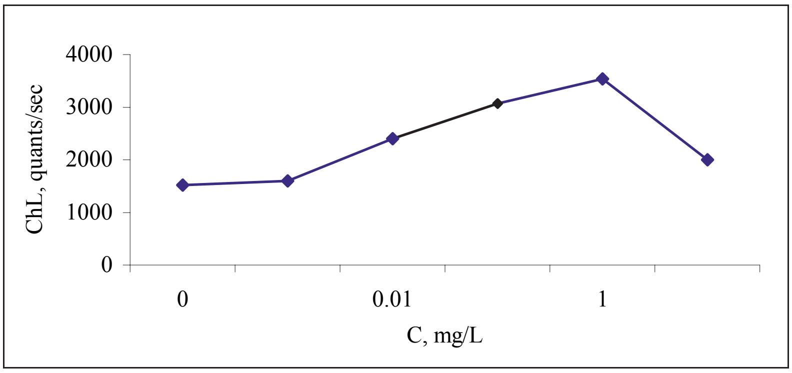


Figure 3. Patulin determination using the biosensor method.

2.1.2. *Method using bioluminescent bacteria as the sensitive object*

We used purified *Photobacterium phosphoreum* K3 (IMB B-7071), *V. fischeri* F1 (IMB B-7070) and *V. fischeri* Sh1 from the Black Sea and Azov Sea of Azov. The level of bioluminescence (BL) was measured using devices shown in Figure 1. The samples contained 0.8 mL of the tested substance in a 2.5% solution of NaCl, 0.1 mL of 0.5 M phosphate (pH 7.0) or phosphate citrate (pH 5.5) buffers and 0.2 mL of bioluminescent bacterial suspension including 5×10^5 cells/mL. In another case, bioluminescent bacteria (10^5 cells) were immobilized in sepharose gel (about 0.1 mL) deposited at the end of fiber optics. In both cases, the BL intensity (I) was registered over a period of 30–120 min. The level of toxicity was presented as the concentration, which caused a 50% decrease in the intensity of BL (EC_{50}). The value of EC_{50} oscillated in the range of 7–19 mg/L depending on the time of incubation of bacteria in the T2 mycotoxin solution. It is necessary to underline that the sensitivity of *V. fischeri* F1 to mycotoxin T1 is much higher in comparison with the sensitivity of *Ph.phosphoreum Sq3* (Katzev et al., 2003).

Increasing patulin concentration from 0.63 to 40 mg/L caused a sufficient decrease in the BL intensity under the influence of *Ph.phosphoreum Sq3* over 12–60 min (Figure 4). The value of EC_{50} for patulin was in frame of 0.63–1.25 mg/L (Pilipenko et al., 2007). The dose-effect of patulin at a low concentration (as low as 1 mg/L) may be confidently registered in the case of three repeated measurements for each point. If it follows this algorithm of analysis the toxic effect of patulin on bioluminescent bacteria may be revealed at a concentration of less than 0.15 mg/L.

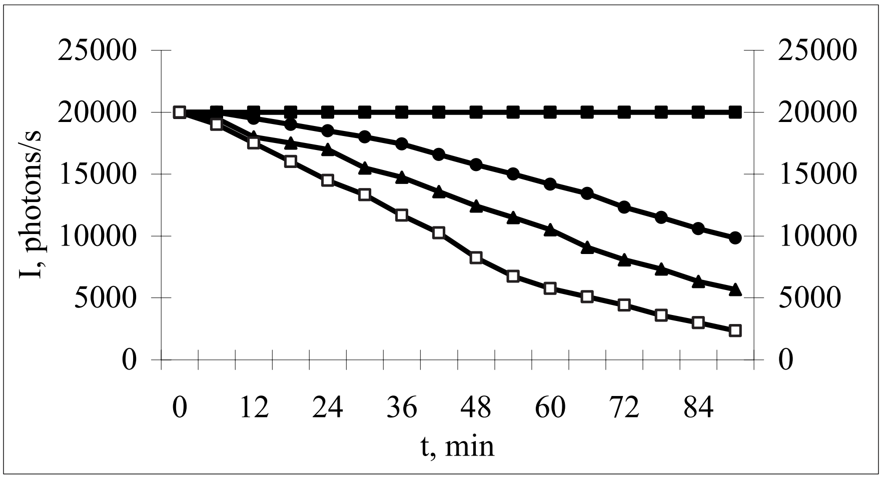


Figure 4. Changes in BL intensity of *Ph.phosphoreum* under the effects of different concentrations of patulin during 90 min, where: 1–4 – 0; 0.15; 0.63 и 1.25 mg/L, respectively.

Moreover with the prolongation of time of influence (up to 90 min) the toxic effect of patulin increased and the value of EC_{50} was in frame of 0.15–0.63 mg/L. When the medium pH was decreased to the lower physiological limit (5–5.5) the sensitivity increased up to one order. The value of EC_{50} is analogous with a semi lethal dose established for animals and it correlates with other indices of toxicity (cytotoxicity, irritation of mucouses, e.a.) (Elnabarawy et al., 1988). It is necessary to mention that the intestinal barrier in animals is destroyed at a patulin concentration of about 1 mg/L (Manfoud et al., 2002). Taking this fact into consideration, the above indicated data testify that the proposed biosensor analysis with the use of bioluminescent bacteria may be effective in screening samples of water, juice, foods and other environmental objects.

In the study of the influence of different types of SAS on the intensity of bioluminescence of bacteria (*Ph. phosphoreum* K3 (IMB B-7071), *V. fischeri* F1 (IMB B-7070) and *V. fischeri* Sh1) it was revealed that the main part of the investigated substances act as inhibitors of this process. The analysis of kinetics of inhibition displayed a number of peculiarities. First, the cationic and anionic SAS had similar kinetics of inhibition. Second, nonionic SAS have an additional stage at which inhibition is absent or some activation of bioluminescence is observed. Therefore, for revealing toxicity of this group of SAS it is necessary to incubate these substances with bacteria for a long time (Starodub and Starodub, 2000, 2001a).

2.2. GENE TOXICITY

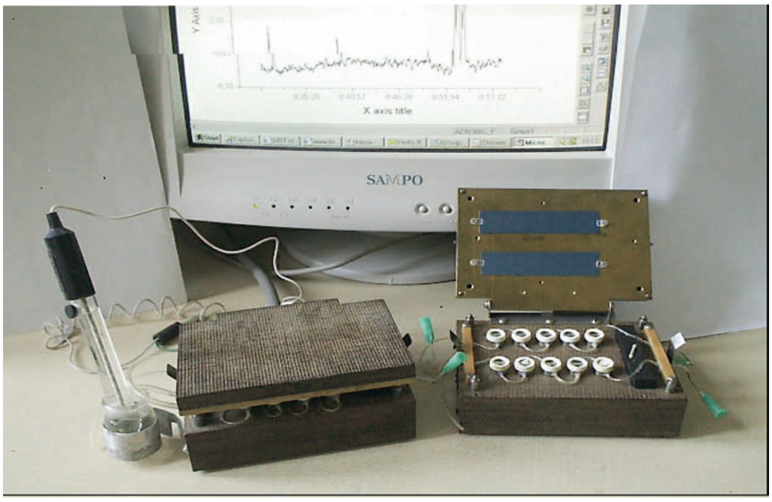
Biosensors for the determination of genotoxicity were developed recently. Their development was stimulated by the desire to have a more sensitive test of toxicity (greater than medium toxicity only) and to have information about gene toxic effects.

It was stated (Guadano et al.,1999) that the mutation of *S. typhimurium* under the influence of 4-nitrogvinoline oxide, methylmetansulphonate and 2-aminoantracene is accompanied by accumulation of ATP. At the same time, a luceferin-luceferase test provides a simple method of ATP-measurement revealing mutation. This approach demands only 9–12 h instead of the 2 days necessary for the traditional method.

Numerous publications (Davidov et al., 2000; Rozen et al., 1999; Kohler et al., 2000; Daunert et al., 2000; Polyak et al., 2000) were devoted to the combination of a routine approach for transferring *lux* genes and a procedure for revealing cell bioluminescence using biosensor technology. These genes are introduced at the promoter of the SOS-system of DNA reparation (*recA*, *recN* or *uvrA*). The influence of gene toxic substances arouses activation of the DNA reparation system and a simultaneous increase in synthesis of proteins which have fluorescent abilities. The analysis may be accomplished with native, dried or immobilized cells. The last variant is most convenient when using biosensors. The cells may be included in different types of membranes: agar/agarose, polyacrilamide, alginate, sol gels, polyvinyl alcohol and other solid phases which are situated at the end of fiber optics or some optical active elements. For the registration of fluorescence special integral systems are used. The development of a system based on fibre optics is documented (Merchant et al., 1998). In such a system as a rule the construction of DPD1718 *E. coli* with *Photorhabdus luminescens lux CDABE* in *recA* promoter is used. At the optimization of the determination of cell fluorescence bacterial cells may reach $1.5 – 3.0 \times 10^7$ in 10 μL of alginate gel situated at the end of fiber optics with a diameter of 270 μm. Introducing this chip into the medium of mitomicine C for 6 h at 37°C, the substance may be registered at a concentration of about 25 μg/L (Polyak et al., 2001).

2.3. BIOSENSOR DETERMINATION OF GROUPS OF TOXIC ELEMENTS

To determine groups of specific toxic substances, for example, phosphor organics, chlorine organics, cyanides and others, we have developed a multi-biosensor based on electrolyte-insulator-semiconductor (EIS) structures (Starodub et al., 1999a). The overall view of this biosensor, the electronic part of which was developed in the Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine, is shown in Figure 5A. One



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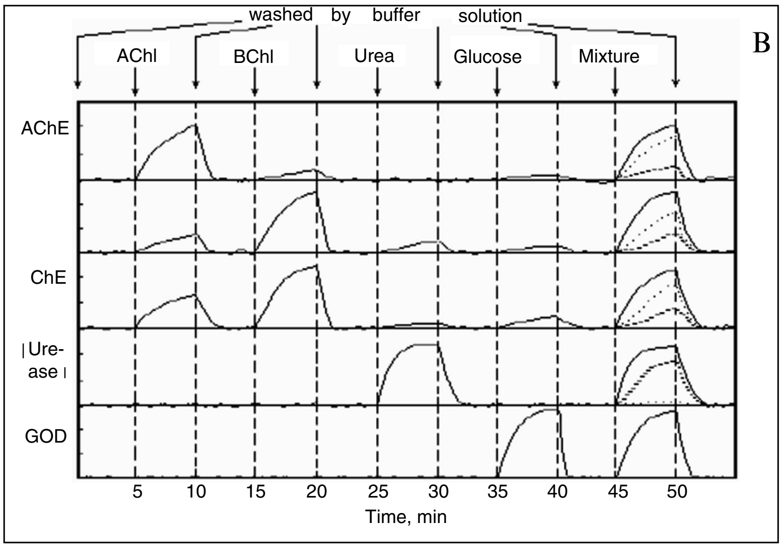

Figure 5. EIS-structures based biosensor (A) and time diagram of the array operation of five different enzyme reactions (B). The mixture contained: $5 \cdot 10^{-4}$ mol/L of Co^{2+}- ions (point-lines); 10^{-5} mol/L of pesticide-bivinyl dipyridine (dashed lines).

of these biosensors is closed and a reference electrode is situated near it. Another biosensor is opened and two independent channels, each of which contains five measuring cells, is visible. The biosensor is controlled by a special computer program.

The principles of design and function of biosensors were presented in Starodub and Starodub (1999a). Specific antibodies to herbicides were immobilized through the staphylococcal protein A. The analysis was fulfilled by sequential saturation when antibodies left unbound after their exposure to native herbicide in the investigated sample then interacted with the labeled herbicide. The sensitivity of the EIS structures based sensor to simazine, when horse radish peroxidase (HRP)-conjugates were used, was approximately 5 μg/L. The linear plot of the sensor response lay in the range of concentration from 5 to 150 μg/L. This sensitivity of the EIS structures based sensor to both herbicides was lower than is recommended in practice. We tried to elucidate the main reasons for such a situation. One of them may be connected with difficulties in registering sensor output due to the formation of air bubbles, which appear as a result of high activity of the HRP. The use of the high concentrations of ascorbic acid may be another reason for the lower sensitivity of this sensor. When we replaced HRP with the glucose oxidase (GOD), the sensitivity of the analysis rose to approximately five times higher. The linear plots for simazine and 2,4-dichlorophenoxyacetic acid (2,4-D) were in the range of 1.0–150 and 0.25–150 μg/L, respectively (Starodub et al., 2000; Starodub and Starodub, 2001b).

An immune biosensor based on EIS structures attracts attention because it offers simple procedures for analysis and the possibility to monitor multiple environmental parameters. For the repeated analysis replaceable membranes are very suitable. The overall time of the analysis is about 40 min. Therefore, the EIS structures based immune sensor may be used for broad screening of the environment for the presence of herbicides. It provides the possibility to analyze 8–10 samples simultaneously. It is suitable for broad screening of not only herbicides but also other types of toxins. Other types of biosensors can be used to validate the results of analysis. For example, based on the IsFETs (Figure. 6) the minimum sensitivity to detect the above mentioned herbicides is 0.1 μg/L or less (up to 0.05 μg/L), which corresponds to practical requirements (Starodub et al., 2000; Starodub and Starodub, 2001b; Shirshov et al., 1997).

We believe that the sensitivity of the EIS structures based immune sensor can be further increased. One of the prospective ways to do this can be the development of special membranes. It is necessary to provide a very high density of immobilized specific antibodies on the membrane surface. Moreover, it would be very effective if these antibodies were immobilized

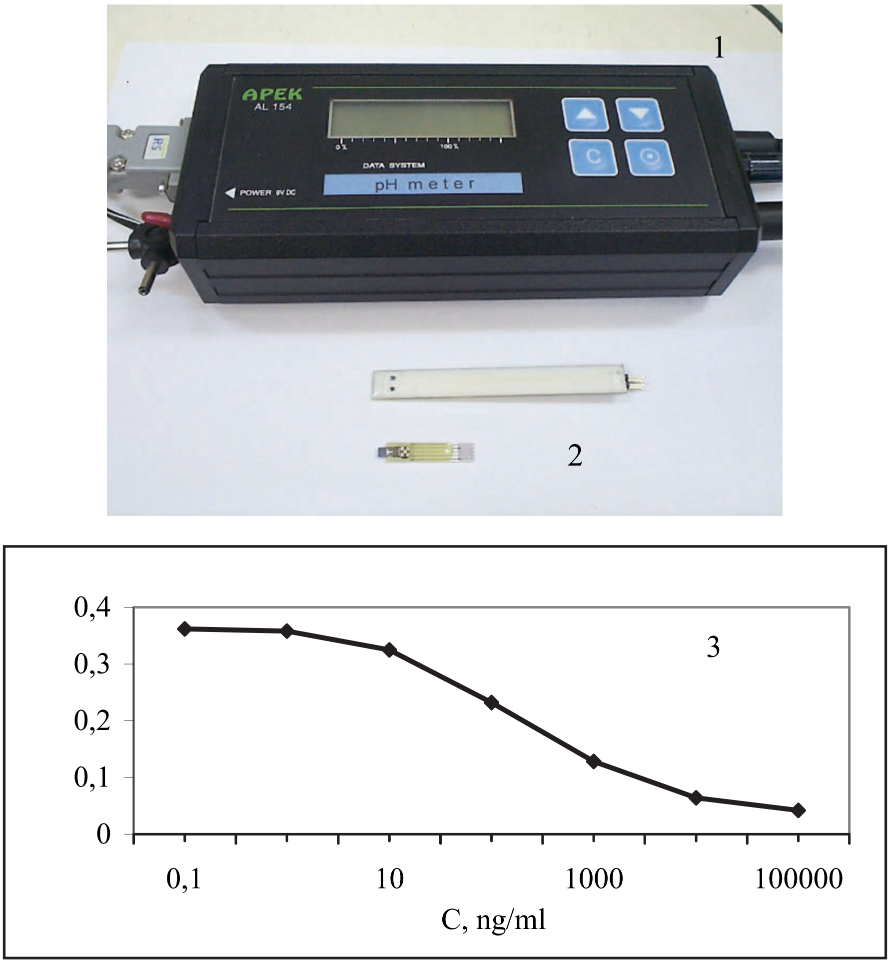

Figure 6. Recording part (1), different types of ISFETs (2) and calibration curve (3) of response of IsFET based immune biosensor in the presence of different concentrations of 2,4-D in solution to be analyzed.

not only on the membrane surface but also in its large-scale pores, which would be accessible to large molecules of conjugates of herbicides with enzymes. In our opinion synthetic biologically compatible polymers, which can be prepared in a simple way with different levels of density and porosity, can serve as a perspective material for such membranes (Rebrijev et al., 2002; Rebrijev and Starodub, 2001). Of course, to increase the sensitivity of the analysis it would be also very efficient to use monoclonal antibodies with a high level of affinity to analytes, to choose enzyme labels with a high turnover of activity and to provide preservation of the enzyme activity during preparation of the conjugate. If the membranes were prepared in advance the duration of the analysis may be shortened by up to 10 min. Membranes are simple to prepare, they are very inexpensive and they can be stored for a long time when refrigerated.

Since a number of enzymes which have serine residue in the active center (first of all butyrylcholine esterase – BChE, acetylcholine esterase – AChE and total choline esterase – ChE) are very sensitive to phosphor-organic pesticides (PhOrPe) and others (urease) containing thiol groups which may react with HMI, there is a possibility to simultaneously determine these classes of toxic elements (Starodub et al., 1998, 1999b).

The sensitivity of HMI and PhOrPe determination essentially depends on the incubation time of enzyme membranes in the environment of these analytes. Two different approaches were tested: (1) registration of the sensor output signal in the mixture of a substrate and analytes, (2) separation of the inhibition reaction from the following measurement of the residual enzyme activity. In the last case the threshold sensitivity of toxin analysis was about 10 times higher. The time of incubation was chosen experimentally at 15 min. The concentration of HMI that could be determined by the urease channel of the sensor array lay within the range from 10^{-4} to 10^{-7} M, depending on the type of the metal used. The range of linear detection covered 2-3 orders of the concentration change. The effects of both pesticides are very similar. The limit of detection of pesticides indicated above was 10^{-7} M. The range of the linear response was from 10^{-5} to 10^{-7} M. At the same time the sensitivity of BChE to HMI was substantially lower than that of urease. The maximum sensitivity of BChE to HMI was for concentrations of more than 10^{-4} M. Activity of GOD depends on the presence of HMI for concentrations above 10^{-4} M. The diagram of the responses of channels with different enzymes (BChE, AChE, urease, ChE and GOD) is given in Figure 5B. GOD was used as a reference enzyme which has a minimal reaction in the presence of both groups of toxins.

2.4. BIOSENSORS FOR DETERMINATION OF INDIVIDUAL TOXINS

For this purpose we apply SPR, TRIE and calorimetric based biosensors.

2.4.1. *Analysis by SPR and TIRE based optical immune biosensors*

The overall view of this biosensor is shown in Figure 7A. The measuring part of it was made in the Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine. The principles of construction of the SPR biosensor and main algorithm of analysis with its help were described in Starodub et al. (1997); Starodub and Starodub (1999b). In special experiments the optimal conditions for analysis were chosen. We have

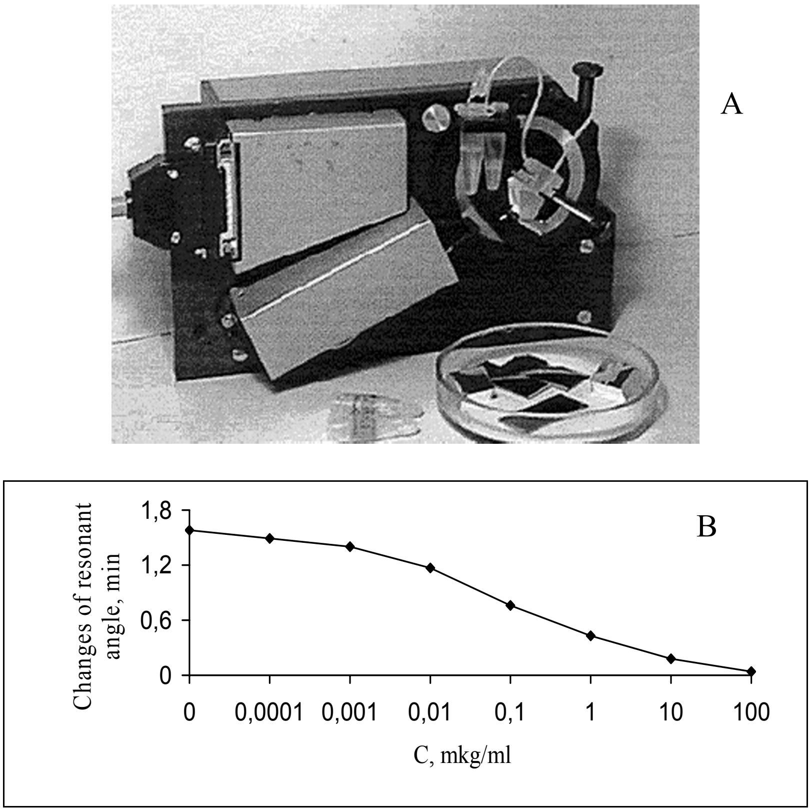

Figure 7. Overall view of SPR based immune biosensor (A) and calibration curves for the determination of nonylphenol by competitive (B) means.

analyzed three main variants of approaches in detail: a) specific antibodies from antiserum were immobilized on the gold surface of an SPR transducer through an intermediate layer of *Staphylococcal* protein A or some lectin, and free analyte was in the solution to be analysed (by way of direct analysis); b) conjugate (nonylphenol, or simazine, or 2,4-D or T2 mycotoxine with some protein – bovine serum albumine, soybean tripsin inhibitor, or ovalbumin – was directly immobilized on the gold surface of an SPR transducer, and free analyte with appropriate antiserum were in solution (competitive means with an immobilized conjugate); c) the specific antibodies from antiserum were immobilized as in “a”, and free analyte and its conjugate with some protein were in solution to be analysed (through competitive means with the immobilized antibodies); and d) immobilized and oriented as in “c”, antibodies react with free analyte and then with the appropriate conjugate (saturation of active binding sites on the surface). It was stated that orientation of antibodies on the surface is more effective with the help of protein A in comparison with the use of lectins. It may be connected with the possibile presence of some carbohydrates not in F_c-fragment of antibodies only, but in F_{ab}-fragments, too.

It can be seen that the sensitivity of 2,4-D analysis by direct means is about 5–10 μg/L, which is not high. Such a low level of sensitivity by direct means of analysis is observed in the case of determination of other low weight substances, for example T2 mycotoxin or nonylphenol. A much more sensitive analysis was achieved by ways designated above as “b” and “d” (Figure 7B). A biosensor based on the TIRE allows us to reveal mycotoxin T2 up to 0.15 ng/mL (Nabok et al., 2005; Starodub et al., 2006; Nabok et al., 2007).

Both optical immune biosensors can provide sensitivity of analysis needed in practice. Overall time of analysis is about 5–10 min if the transducer surface is prepared beforehand. It is necessary to mention that the immune biosensor based on the SPR is simpler then TIRE biosensor. In addition, it may also be made into a portable device.

2.4.2. *Analysis using calorimetric immune biosensors*

This biosensor was designed in two different forms: as a micro calorimeter and a thermistor based device (Figure 8A). Efficiency of the immune biosensor for the determination of low molecular substances we will demonstrated by the results obtained in experiments with nonylphenol.

For successful development of the calorimetrical biosensor, at first it was necessary to set the optimal concentration of antiserum (for example antiserum to nonylphenol). For this purpose 150 μL of antiserum in different concentrations was put in a measuring cell and incubated for 15 min in order to establish the baseline (for this time the ambient temperature was set at an optimum level). Then 50 μL solution of nonylphenol in concentrations of 1, 5 and 10 μg/mL were brought into the cell. Thus, it was determined that the optimum concentration of antiserum was about 5 mg of protein in 1 mL.

For the determination of nonylphenol in solutions with the help of a thermal biosensor it was necessary to build up a corresponding calibration curve. For this purpose 150 μL of antiserum (in concentration 5 μg of protein per 1 mL) was put into a measuring cell and then 50 μL of nonylphenol in a range of concentration from 0.5 up to 10 μg/mL and pumped into the measuring cell (Figure 8B). Thus, an opportunity of “direct” detection of nonylphenol by calorimetrical biosensor with sensitivity of about 1 μg/mL was demonstrated. The overall time of analysis is about 20–30 min.

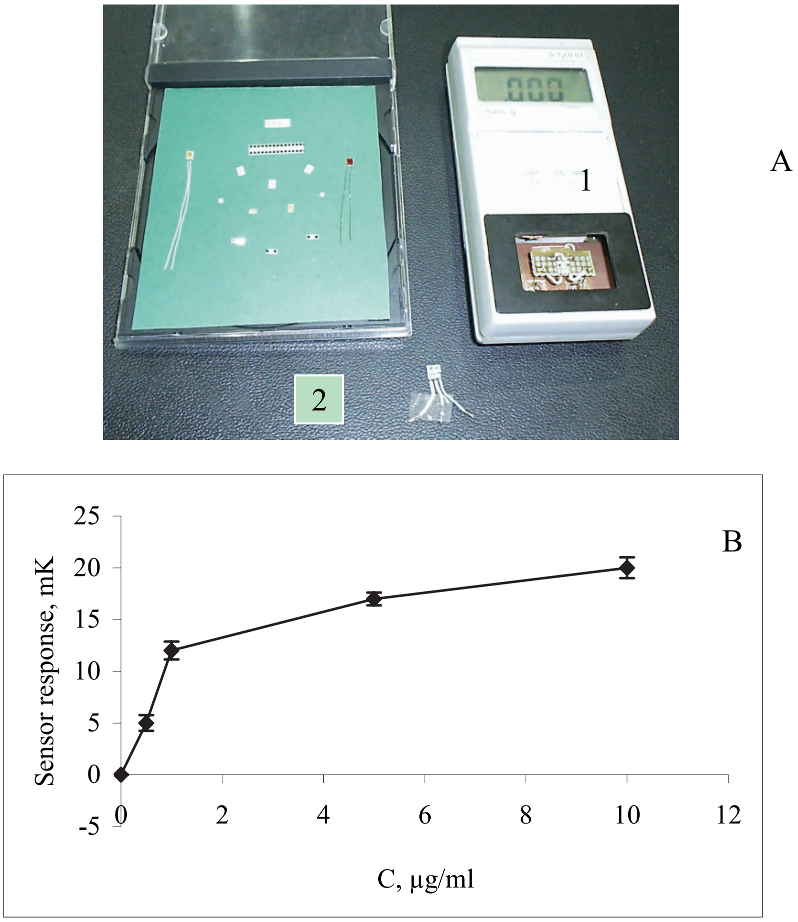

Figure 8. Overall view of portable biosensor based on thermistors (A) and “direct” detection of nonylphenol by the calorimetrical biosensor (B). 1 – portable recording devices, 2 – thermistor.

Certainly the sensitivity of the determination of nonylphenol by thermal immune biosensor is much less than that of SPR or TIRE biosensors, but it is necessary to mention the simplicity of measurement. It is possible that thermal biosensors could be used to screen toxic elements in environmental objects with subsequent verification of results of analysis using optical immune biosensors.

2.4.3. *Detection of formaldehyde*

This substance is very dispersed as result of industrial manufacturing and natural origin. It is found in vegetables, fruits, raw meat and in different biological liquids (Feron et al., 1991). The accumulation of aldehydes, including formaldehyde, in an organism may stimulate cancerogenesis and apoptosis (Tyihak et al., 1998). In a number of works (Gonchar et al., 1992; Korpan et al., 1993, 1994, 1995) methylotrofic yeast with defective synthesis of formiatdehydrogenase and formaldehydreductase, which are able to extrude protons, was chosen. When the *Hansenula polymorpha* cells were immobilized in alginate gel, a biosensor was situated at the gate surface of IsFETs, which allowed the determination of formaldehyde in the frame of 2–200 mM of concentration (Korpan et al., 2000). Certainly, the sensitivity of this biosensor depended on buffer capacity, ionic strength and pH. Moreover it was sensitive to sodium azide, actinomicine and vanadate.

The development of amperometrical and optical biosensors was communicated in a number of publications (Hall et al., 1998; Winter and Cammann, 1989; Rindt and Scholtissek, 1989). In amperometrical biosensors formaldehyde dehydrogenase was used as the sensitive element. Unfortunately they have a disadvantage, since it is necessary to include special cofactors and mediators.

2.4.4. *Control of cyanides*

A lot of methods were developed for the detection of cyanides. We will devote our attention to only some of them. In the first case, a column chemosensor was developed based on the combination of an ion-exchanger reactor with immobilized luminol and cation exchanger reactor with copper ions (Lu et al., 1995). This chemosensor is capable of analyzing water from melted snow and waste water. It has a sensitivity of about 2×10^{-9} g/L and the time of analysis is 1 min. After regeneration of the column using a solution of NaCl, the sensor may be used up to 200 times.

For concentration of cyanides present in the air, air is passed through 0.1 M solution of NaOH and then, using special membrane in which quaternary complex of Co (II), α,α'-dipyridyl and ethanolamine is formed. The quantity of this complex may be determined by polarography. The sensitivity of analysis is 6.0×10^{-9} M (Zhang et al., 1999).

For the determination of potassium cyanide a microbial sensor was developed (Palmqvist et al., 1994). Another original biosensor was proposed using South American tropical fish *Apteronotus albifrons* as the sensitive object. It had sensitivity on the level of 35 μg/L of potassium cyanide (Clement and Yang, 1997).

2.4.5. *Determination of volatile hydrocarbonates*

Volatile hydrocarbonates form a large set of OChS, and the most of them are very dangerous for living organisms. The ELISA-method and an optical immune biosensor were developed for the determination of these substances (Chuang et al., 1998; Vo-Dinh et al., 1987). A very original biosensor based on the measurement of photosynthesis of membranes of *Chlorella vulgaris* cells was developed for the determination of toxic substances directly from the air without conversion using a water medium (Naessens and Tran-Minh, 1999). Cells in close contact with an oxygen electrode and a sensor element were placed in an illumined chamber with the air sample to be analyzed. Maximal response was achieved in 30 min. The sensitivity of perchloroethylene was on the level of 50 ng/L. Fifty percent of biosensor activity was lost after 8 days. Moreover it did not reversibly react at the concentration of 340 ng/L. Genetically modified *E. coli* cells were used for the determination of benzene derivatives (Kobatake et al., 1995). With this purpose a gene of luciferase was introduced in TOL plasmide of *Pseudomonas putida*, which has *xylR* and *xylS* genes coded for the number of enzymes taking part in the degradation of benzene and its derivatives. In such way a new pTSN316 plasmide was constructed and transferred in *E. coli* cells. In the presence of aromatic substances the expression of luciferine is induced. Its luminescence is determined according to common procedure. The sensitivity of analysis was less than 5 μM of xylene.

2.4.6. *Determination of phenols*

Maximal permissible concentrations of phenols in untreated and chlorinated waters are 0.1 and 0.001–0.002 mg/L respectively (Experiandova et al., 1999). Among biosensors intended for phenol determination, enzymatic ones are the most widespread. About 23 enzymes were examined as sensitive structures. Only five of them, namely: lactate dehydrogenase, phenylalanine dehydrogenase, glycerol-3-phosphatdehydrogenase, hexokinase and pyruvate kinase, were sensitive to the above mentioned OChS (Cowell et al., 1995).

The application of tyrosinase was described for the determination of phenols (Li et al., 1998). An enzyme was immobilized in a layer of sol gel, which was prepared as a result of hydrolysis of tetrametoxysilane with simultaneous condensation of it until the formation of oxybridges. The sensitivity of analysis was about 1.53, 1.28, 1.05, 0.687, 0 and 0 for catechol, phenol and *p-, m, o*-cresols, respectively. The measurements were fulfilled by cyclic voltametry in diapason from 300 to –200 mV (at the interval of 5 mV/s) with application of carbon paste as the electrode and without a mediator. Unfortunately about 50% of electrode activity was lost during 15 days using preservation in a phosphate buffer at 4°C.

The similar variant with a carbon electrode and a silicon sol-gel membrane modified using oxide titanium was developed on the basis of peroxidase (Rosatto et al., 1999). In this case direct electron transfer with help of peroxidase was blocked in the presence of phenols. The sensitivity of this biosensor was about 1 μmol/L.

The original portable biosensor in form of a disposable bioprobe for semi-quantitative estimation of water contamination by phenol was proposed on the basis of phenol oxidase immobilized together with 3-methyl-2-benzotiasolinon hydrasine on a nylon membrane (Russell and Burton, 1999). In the presence of phenol, the membrane had a dark vinous color, and in the presence of cresol it was orange. The enzyme activity did not change in a broad range of pH (4–10), temperature (5–25°C), concentration of salts and metal ions. The sensitivity of analysis was about 0.05 mg/L. The working period of this biosensor was 1 month without any enzyme inactivation.

A fiber optic biosensor was developed on the basis of enhanced chemiluminescence in the system of luminal-hydrogen peroxide-peroxidase (Ramos et al., 2001). The enzyme was immobilized in a silicon sol-gel membrane. The sensitivity of this biosensor to *p*-iodphenol and *p*-coumarin acids was 0.83 μM, 15 and 48 nM respectively.

2.4.7. *Revealing surfactants*

To determine such surfactants as Triton X-100 and sodium dodecylsulphate (SDS) an electrochemical sensor was developed in which the carbonate working electrode was covered with a mixture of Nafion and polyvinylsulphonate (Brett et al., 1999).

An electrochemical biosensor with surfactant degradable bacteria immobilized on the oxygen electrode was proposed in Japan already in 1994 (Nomura et al., 1994). In the presence of anionic surfactants, the oxygen consumption increased up to a concentration of 6 mg/L. The specificity of this biosensor was checked in experiments using other types of microorganisms in parallel with the application of a standard method based on highly effective liquid chromatography with fluorescent detection (Nakae et al., 1981). It was shown that the coefficient correlation between data obtained by the biosensor and the standard method was equal to 0.98, and the level of the sensitivity of both methods was 0.1 and 0.2 mg/L, correspondingly.

Investigations into the application of biosensors for the detection of anionic surfactants were conducted in Kiev (Reshetilov et al., 1997; Taranova et al., 2000). In this case, bacteria strains *Pseudomonas* and *Achromobacter* were immobilized in agar gel on the surface of the oxygen electrode. It was shown that some bacteria had high selectivity to individual surfactants, and sensitivity to such substances as SDS, alkyl-sulfonate and sodium-2-alkanamidoethane sulfonate was in the frame of 0.25–1, 10 and 10 mg/L, respectively.

The efficiency of applying different types of transducers (including the standard oxygen electrode, the glass electrode and IsFETs) was compared with various principles of the registration of generated signals at the determination of SDS in solution using cells of *S. cerevisiae* as the sensitive element (Campanell et al., 1997). It turned out that the registration oxygen consumption provided sensitivity up to one order higher in comparison with the determination of excretion of CO_2 or hydrogen protons.

3. Conclusion

Today, protection of the environment from contamination by OChS demands great attention and global actions as in the recent case of the ozone problem. Certainly, the role of biosensors in the control of environmental objects increases every year as far as possible to improve their technical and analytical characteristics and to move closer to the most complete fulfillment of practical demands. It may be achieved to the maximum in the case of the development of multi-parametrical systems which will be able to analyze several probes and to detect a wide range of different substances. This may be achieved through the application of hybrid organic- and non-organic sensor technologies as well as use of thin layer technology (Beschr and Mackenzie, 1998; Lucklum et al., 1996). Chemical modeling of the selective biological sites for the binding of analytes is a very important step in the development of a new generation of instrumental analytical devices (Ritter et al., 2001; Kalchenko et al., 2003). In this respect, calixarenes are a very promising compounds. They are presented by a very large group of individual variants, and it is possible to choose some among them which have the highest affinity to concrete toxins. Some confirmed results are shown in Table 2.

TABLE 2. Constant (Ka) complexes of "host-guest" at the interaction of 2,4-D, atrazine and T2-mycotoxin with calixarene.

"Guest"	Types of calixarene					
	1		2		3	
	K_a	% of RSD	K_a	% of RSD	K_a	% of RSD
2,4 D	3,657	6.18	772	24.22	5,077	6.64
Atrazine	6,785	7.32	2,513	26.58	6,483	9.07
T2 mycotoxin	550	28.10	8,850	4.02	1,020	25.40

Certainly in the creation of a new generation of biosensors, it is necessary to develop new, more effective membranes which will remain stable over long periods of work of the analytical devices in different media (Desai et al., 2000).

When all of the above mentioned problems are solved, ecological services will be provided by the reliable analytical instruments. Nevertheless, even today it is possible to give a positive answer to the question posed in the title of an article published in the journal "Biosensors" about 20 years ago: "Can biosensors help to protect drinking water?" (Evans et al., 1986).

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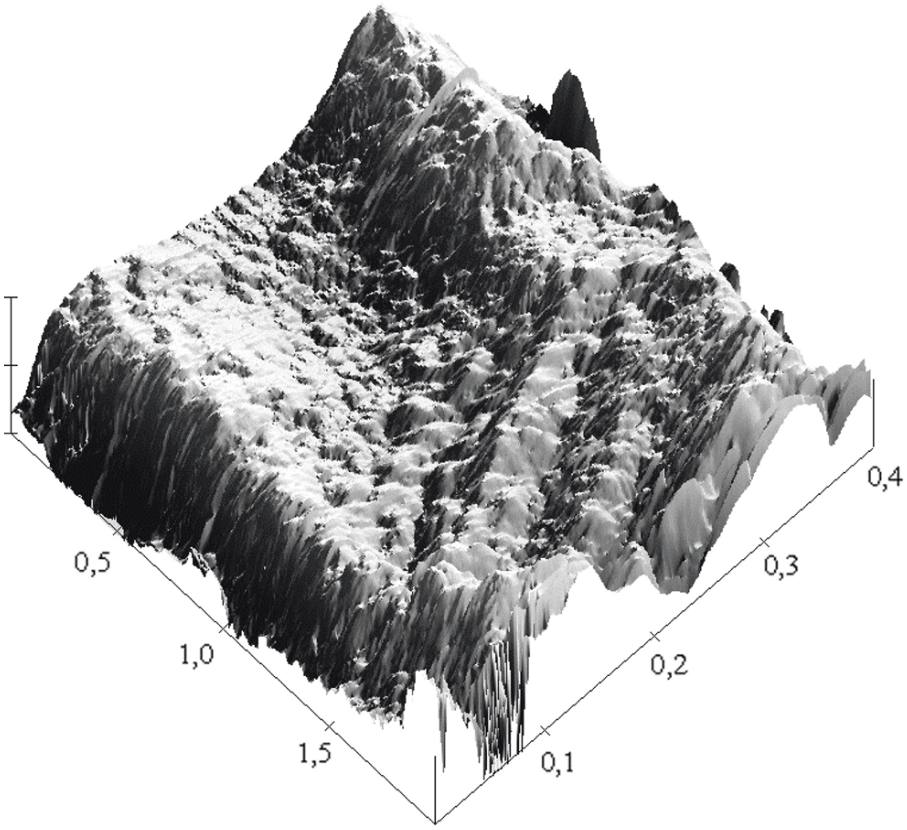

Image of porous silicon surface with antigen-antibody complex using atomic force microscopy.

MONITORING RANGELAND ECOSYSTEMS WITH REMOTE SENSING: AN EXAMPLE FROM KAZAKHSTAN

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Abstract. This paper describes the nature and problems of rangelands in Kazakhstan. A prototype rangeland monitoring program based on an existing monitoring program developed for use in the Soviet Union is described. The monitoring approach has been modified to use the same simulation model, but more modern remotely sensed data is being incorporated into the approach as well. Results from the Balkhash area of Kazakhstan are presented to show progress to date. Current plans are to continue to develop this approach for the study area, and if feasible, apply the approach nationally.

Keywords: Pastureland, desertification, monitoring, modeling of pasture ecosystem, remote sensing, total vegetation index

1. Introduction

Kazakhstan range and pasture lands are semi-natural ecosystems, which have been formed as a result of domestic and wild animal grazing. The total pasture area in Kazakhstan is 187.2 million hectares, including 40% desert

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pasture. Kazakhstan's natural pasture vegetation has been greatly harmed by desertification. Of the main natural factors facilitating desertification of pasturelands, soil salinization and wind erosion are the most evident. Kazakhstan's desert receives more than 6,000 MJ/m^2 of solar radiation and a total of 160–300 mm atmospheric precipitation per year and has a mean annual wind speed of 2–3 m/s. In these conditions, water loss due to evaporation is several times larger than water input. Consequently, in this stressful environment, the main forms of natural desertification, such as soil salinization and wind erosion, progress in the desert zone. The wind causes sand and light sandy soils to be unstable because plant cover takes several centuries to form.

The natural desertification processes in Kazakhstan have become more prevalent because of human activities. Human pressure on pastures, in general, is reflected by pastureland degradation. At the beginning of the 1990s the number of sheep reached 35–36 million in Kazakhstan. Of course the stocking is not uniform, and some regions have very high stocking rates. As a result, changes in the soil and plant cover of the desert zone were observed across more than 60% of Kazakhstan. Such high stocking rates could not be maintained, and by the middle of the 1990s the number of sheep had decreased to 11 million (17 million in 2006). However, the degradation of Kazakhstan's pastures continues, as water points for animals are limited and the sheep are concentrated near human settlements. These pressures result in reduced soil fertility, loss of plant biodiversity and reduced productivity of forage vegetation (Figure 1).

Figure 1. Desert pasture vegetation on plains with clay or sand soils has productivity of 0.2–0.4 t/ha.

2. Bioecological characteristics of desert vegetation in Kazakhstan

As a result of harsh environmental conditions and natural selection, the deserts of Kazakhstan are host to some 1,200 species of plants. Of these, however, only a few tens of species are dominants or subdominants forming discrete plant communities on pastureland (Bykov, 1978). These species are perennial shrub, dwarf shrub, subshrub and dwarf subshrub species, and perennial and annual forb and grass species. A distinctive group with a short growing period in spring is represented by the ephemerals. Desert plants have developed a degree of resistance to environmental conditions. They are principally mesotrophic and oligotrophic species, plants adapted to poor soils. Deserts, which often have saline soils, are host to many salt-tolerant plants, or halophytes. Sands are home to psammophytes, plants adapted to life in a shifting environment. Depending on their resistance to drought conditions, most plants in desert zones are xerophytes, able to withstand very dry conditions of air and soil. Most of them also withstand high air and soil temperatures and are thus thermophilic plants (Kurochkina, 1978).

Depending on the way they take up moisture, most desert plants may be classified as ombrophytes, trichohydrophytes or phreatophytes (Bedarev, 1968). Ombrophytes are a group of plants whose root system is located in the surface layer of the soil and take up water directly from precipitation. Trichohydrophytes have complex root systems that penetrate fairly deeply into the soil (2–3 m and more) and take up groundwater by means of capillary action. Phreatophytes have thick roots that tap directly into groundwater.

Depending on the time-scale involved, plants may be classified as very early, early, mid-range and late developing species. In the deserts of Kazakhstan, growth of very early and early developing plants starts from late March to early April when the air temperature reaches 3–5°C. Growth ends 1–2 months later after the plants have seeded. Mid-range developing plants stop flowering and produce seeds 2–3 months after the onset of growth. Late developing plants resume growth in the spring when the air temperature reaches 10–12°C, flowering only in midsummer and producing seeds in late summer or in the autumn.

The growing season of desert plants may be divided into a period of active growth, a maintenance period and a period of senescence (Larin, 1969). The period of active growth, which generally begins once the air temperature reaches 10–12°C, is associated with active photosynthesis. Photosynthesis leads to a build-up of organic substances in the form of assimilants and the individual parts of the plant show active growth. In the conditions prevailing in the deserts of Kazakhstan, the period of active growth coincides with the period when the plants are standing and green, but may occasionally also occur in the development phase in an unusually wet year when temperatures have been mild. In such years, the period of active growth is prolonged and ends at seeding. This is the time when the yield of pastureland plants is at its height. After this, growth comes to a halt until seeding has ended. This is the maintenance period.

However, it is much more common for the period of active growth in herbaceous plants to end prematurely when the temperature reaches 18–20°C. Shrubs and sub-shrubs are observed to lose leaves and twigs when the temperature reaches 22–24°C. In such years, the generative phase of desert plant growth does not come to a successful conclusion or is not observed at all. Early withering of plants during the summer results from disruption of their water balance due to inhibition of assimilation caused by high temperatures and insufficient moisture. Biomass fails to increase, although it may be conserved in such a period, only to subsequently wither and fall.

These processes, which are due to the destruction of chlorophyll-containing tissues, may also continue into the cold period of the year. The lengths of the periods of active growth and senescence, which are governed by the biological properties of the plant and by agrometeorological conditions during the year, vary widely. In good years with sufficient moisture, active growth in the very early groups of ephemerals is 50–60 days, while for late-developing plants, the growing period is 120–150 days. In exceptionally dry years, active growth in the spring period lasts no more than 20–30 days for early-developing plants and 50–60 days for late-developing plants. By late summer or early autumn, when the temperature falls to 20–22°C, plant growth interrupted by the summer may resume. Herbaceous plants will start growing again following rain greater than 10 mm (Phedosseev, 1964).

3. Monitoring and modeling pasture ecosystems

Pasture monitoring in Kazakhstan includes:

- Systematic geobotanic field studies on large areas performed by the Republic of Kazakhstan Land Use Agency until 1993 and more limited studies in later years.
- Episodic specialized (geobotanic, soils, agricultural and ecological) observations on limited areas of Research Institute desert research sites.
- Regular point observations by the RSE "Kazhydromet" meteorological station network in dry areas, which are limited by some plant associations.
- Remote sensing and visual observations of vegetation seasonality by RSE Kazakh Research Institute and Ecology and Climate expeditions conducted regularly prior to 1993 and occasionally in later years.

The task of pasture monitoring is complemented by modeling the dynamics of natural vegetation over large areas through the use of quantitative data provided by remote sensing. Modeling natural biocenoses, generally a group of plant species each with its individual response to environmental conditions, is a difficult task. The difficulty here is that the model often contains parameters relating to actual plant species and their actual habitats while remote sensing frequently provides only an overall view. This is why in modeling large areas of pastureland the focus has been on relatively simple models based on a small number of parameters and a restricted amount of input information. As a result, these models may, more properly, be considered as applied models. Work with these models is thus often carried out at the level of vegetation zones, most usefully in relation to separate type groups (Tucker, 1980; Lebed and Turbacheva, 1990). The usefulness of this group of models increases when they contain meteorological, soil, and other variables that control the physical processes.

An applied model for estimating the yield of large areas of desert pastureland has been developed in Kazakhstan (Lebed and Belenkova, 1995). The model was officially approved for use in a wide-ranging aerial and space experiment carried out on part of the Priaral (land bordering the Aral Sea) in 1990 and 1993 and has given acceptable results for use in practice.

The present model takes the resumption of growth in the biomass of plants above ground during the year as an overall indicator of the pattern of change in the desert pasture ecosystem as a whole. The results are taken to be the pasture yield, expressed as tons per hectare dry weight. The model relies on digital and video models of spectral reflection from pastures provided by periodic aerial and space surveys. Routine agrometeorological data provided by the station network and cartographic information provided by geobotanical surveys are also used. The model is also used to derive other recognized quantities such as potential and actual yield, as previously determined in relation to agricultural crops (Thoming, 1977).

In the case of pasture ecosystems, the vegetation prevailing at the present time, including species composition, structure and yield, is the direct result of climate, relief, hydrography, soil type, plant pest activity and other environmental factors. Hence, its potential yield is the maximum yield possible given the soil, climate and other natural resources of the locality. At the same time, plants are affected by indirect or redistributive factors, the chief of which are human activity and current weather conditions. Increased human input may bring changes, often of an irreversible nature in the species composition, structure and yield of pasture vegetation (Nechaeva, 1981; Kurochkina, 1978). As a result, most present-day pastures may be termed semi-natural ecological systems (Vinogradov, 1984). Weather is another redistributive factor that determines current seasonal and yearly changes in natural vegetation. However, in contrast to human intervention, such changes are generally reversible in nature. They appear each year as annual changes in the biomass produced above and below ground, in partial shifts in vegetable structure, changes in seed quantity and differences in the amount of new growth in pastures. Weather conditions are associated with what is termed the yield per agrometeorological year. This parameter in its turn is affected by the grazing of stock in different seasons, sometimes for long uninterrupted periods. A portion of the annual yield is lost by withering during senescence. The resultant amount is close to the actual yield of the pasture per agrometeorological year. The actual yield includes the yield from green growth.

Here, the process of quantifying the actual yield of a desert pasture may be described as successive biological and physiological processes associated with the build-up and collapse of plant biomass in the course of the year. In practice, for different species and plant groups, these processes take place at different seasons of the year and last for different lengths of time.

The build-up of plant biomass as a result of growth during the current year is modeled by means of equations of the general type:

$$y_{\alpha\tau} = \frac{y_{pot}}{1+\left(\frac{y_{pot}}{y_\tau}-1\right)\exp\int_0^t R\,t\,dt}, \quad (1)$$

$$R_\tau = R_{\max} \cdot A_\tau, \quad (2)$$

$$A_\tau = f(F,T,W), \quad (3)$$

Where:

$y_{\alpha\tau}$ – yield in the period of active growth during the agrometeorological year (in t/ha)

Y pot – real potential yield (in t/ha)

y_τ – actual yield in the period of senescence (in t/ha)

R_τ – plant growth function

R_{max} – value of R_t under optimal environmental conditions

F,T,W – environmental factors (light, heat, moisture) (in MJ/m^2, °C, mm)

τ – time of year (in days, decades, month)

The process of biomass collapse may be expressed by the equation:

$$y_\tau = y_{\alpha\tau} \cdot \exp a_\tau \quad (4)$$

where,

aτ – rate of biomass collapse

The process of build-up and collapse of biomass is limited by the critical values of the regime factors affecting each species and group of plants. Calculation of biomass is carried out in variable stages of 5, 10 or more days. Here, the mass representing new growth and seeds is not deducted from the total biomass since they represent a relatively small (<10%) part of the total yield and do not significantly affect its measurement.

4. Parameterizing the pasture yield model

In determining the parameters of the pasture yield model, the authors, like other researchers (Kirsta, 1986) have assumed that the response of natural vegetation to change in such environmental factors as weather conditions is fairly consistent. It was also assumed that moderate grazing would not have a noticeable effect on the pattern of plant growth and development arrived at in the course of evolution. At the same time, account was taken of the response of pasture ecosystems to human activity, which could have both beneficial and harmful effects on soil and plant cover. In recent years the effect of human activity on pastureland in Kazakhstan has been associated with marked changes in stocking rates, possible changes in the pasture management system, measures for improvement of pastures and other forms of action.

In this connection, a number of the model parameters reflecting the biological laws governing the development of plants and their response to light, heat and moisture (C_F, C_T, C_W) have been calculated outside the time-scale and geographical location of the vegetation modeled. In determining these parameters, the authors used data from observations of pastureland collected over many years at permanent field sites as well as paired agro-meteorological observations made at meteorological stations and temporary sites. These observations were carried out directly by the authors of the model and other research workers in the desert zone of Kazakhstan in the period 1960–1980. For example, Table 1 gives the constant parameters of the model for individual plant species in a sandy desert. Similar results have been obtained for the principal dominant plants found in the desert zone of Kazakhstan.

A biological parameter of the model such as potential yield, Y_{pot}, will take on numerical values for each natural region with its own species composition and vegetation structure. It is determined from data giving the actual yield of vegetation in the green state, which may be obtained either by direct field observation or air or space imaging of pastureland during the growing season. A practical example of the results given by calculating Y_{pot} for pastureland in the Priaral from the results given by remote sensing is shown in Table 2. The optimum repetition interval for calculation of the parameter, Ypot, is the same as that for pasture geobotanical surveys, 5–7 years (Vinogradov, 1984).

TABLE 1. Parameters of the model being used for calculation of the yield of individual dominant plants in desert vegetation.

Plant species	Parameters						
	t	R_{max}	ΔW	Cw	ΔT	C_T	a_τ
Agropyron sibiricum	4	2.10	0.40	0.40	10	0.50	
	5	2.20	0.60	0.60	7	0.35	0.30
	6	2.10	0.60	0.75	7	0.35	0.70
	7	1.25	0.60	1.00	7	0.35	0.80
	8						0.90
	9						
Artemisia terrae albae	4	1.95	0.40	0.40	10	0.45	
	5	2.15	0.65	0.85	7	0.33	
	6	2.20	0.80	1.00	7	0.33	0.60
	7	1.95	0.80	1.33	7	0.33	0.75
	8	0.70	0.80	1.33	7		0.95
	9	0.70	0.80	1.33	7		0.50

TABLE 2. Potential yield of pasture vegetation (Ypot) in the Northern Priaral calculated for the different geobotanical regions on a map with a scale 1:2,500,000 in 1990.

Division and vegetation	t/ha
Artemisia spp. and Halophytic with ephemerals on brown clay soils on hummocky flatlands *(Artemisia terrae albae, Anabasis salsa)*	2.66
Halophytic and Artemisia spp.with ephemerals on clayey saline soils on undulating flatlands *(Atriplixae capae, Anabasis salsa, Artemisia terrae albae)*	0.90
Halophytic and Artemisia spp. on clayey saline soils and sandy soils on undulating flatland *(Kochia prostrata, Anabasis salsa, Artemisia terrae albae)*	2.71
Artemisia spp. and grasses with Halophytic and ephemerals on clay and sandy loam soils on pre-sandy undulating flatland *(Artemisia terrae albae, Agropyron sibiricum, Poa bulbosa)*	1.41
Artemisia spp. and grasses with Halophytic and shrub on clay soils *(Artemisia terrae albae, Kochia prostrata)*	1.03
Shrub and Artemrsia spp. and grasses on the hilly ridged sands *(Artemisia terrae albae, Agropyron sibiricum, Calligonum)*	2.50

The model makes it possible to calculate the yield of pasture vegetation at different sites ranging from a few acres hosting specific plant communities to hundreds or thousands of hectares representing specific geographical landscape types or geobotanical vegetation regions. The outcome is a series of curves representing changes in the biomass of vegetation of the current year's growth throughout the growing season, in the fodder stocks on pasture-land at different seasons in the bioclimatic potential and bioecological condition of pasturelands, and in other indicators.

A working variant of the model can be used under different regimes, including operational studies for forecasting yields during the growing season (Figure 2) over a complete year and retrospective studies to calculate pastureland yields from agroclimatic data. The usefulness of the initial results given by the model is increased if they are further processed to give a map of fodder yields or biological productivity.

Information on pasture yields is of practical use in moving stock on pastures and improving stocking rates on areas of ecologically poor pastureland. It can also be used in decision-making on agricultural and ecological issues with a bearing on evaluation of the country's natural resources and preparation of socioeconomic development programs for desert regions and ecological programs. Pasture monitoring and modeling can be used as practical tools made possible by modern remote sensing systems and algorithms for the analysis of geospatial information.

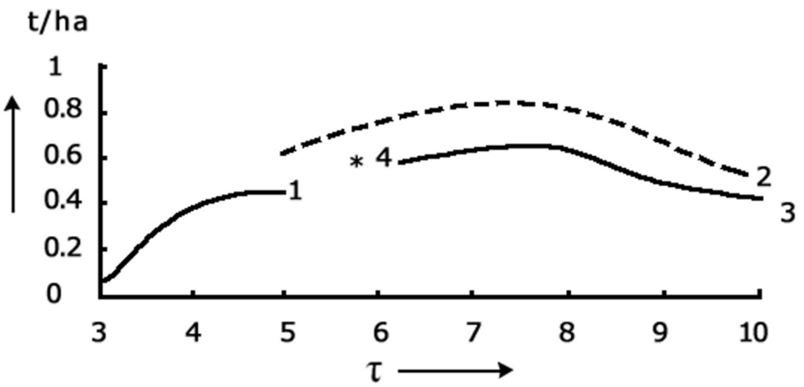

Figure 2. Forecast yield (t/ha) of *Artemisia* spp. and salines on clay-soils on flatland in the Northern Priaral throughout the 1993 growing season (Lebed and Belenkova, 1995). Calculations made on 10 May (1), 10 June (2), 10 July (3) result of aerial survey (4).

5. Current research and preliminary results

We are currently developing a prototype modern rangeland monitoring program based on a simulation model as well as field and remotely sensed data. Figure 3 shows the flow of information in the processing steps undertaken by the International Science – Technology Center Project funded by the United States Department of Agriculture to collaborate on research to improve the monitoring and modeling of rangeland vegetation in Kazakhstan. Recent research in the southwestern United States has shown that it is possible to quantify grassland cover, height and biomass even when the grasses are senescent using Landsat 7 imagery (Qi et al., 2002). The approach uses field measurement of key parameters to estimate a soil adjusted total vegetation index (SATVI), which is in turn used to estimate cover using an empirical relationship from the field data. Grass height is estimated empirically using an empirical relationship to the NIR band. Biomass is then calculated using the product of the cover and height and an empirical correction factor. Preliminary research indicates that the same approach can be used in parts of Afghanistan and China. A map of estimated 2006 biomass for rangelands in the Balkhash area in Kazakhstan is shown in Figure 4.

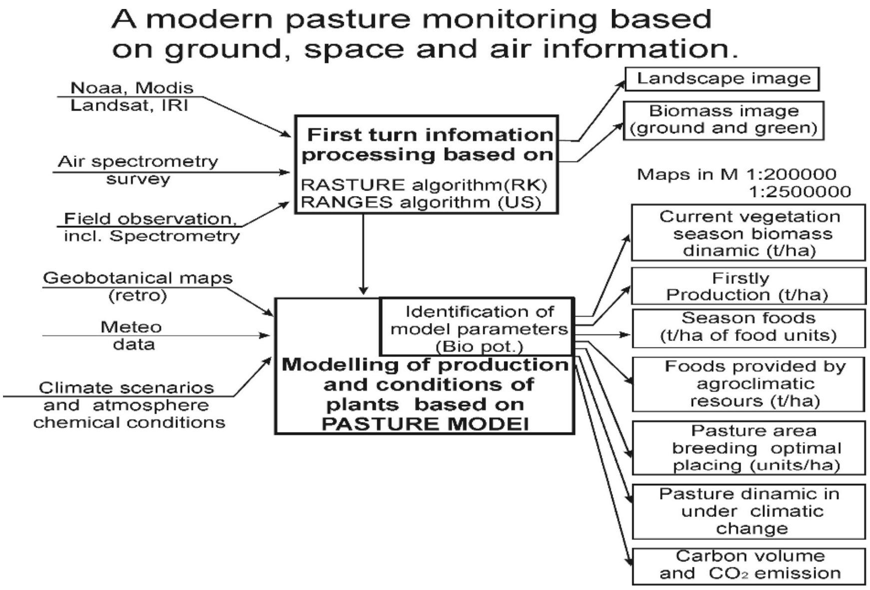

Figure 3. Flow of rangeland monitoring processes.

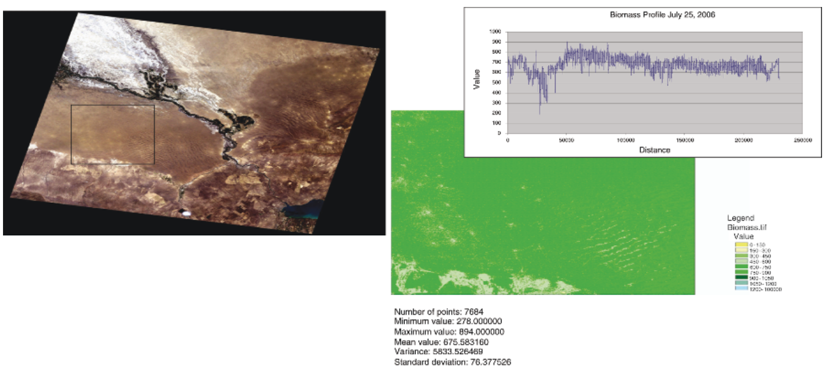

Figure 4. Preliminary results of the Landsat image processing.

6. Future research

Rangelands are an extensive but critical resource. Modern tools such as remote sensing and simulation modeling, in addition to field data collection and geospatial databases, should harness information from all sources to provide better information about spatially distributed patterns of plant production for decision making. Remote sensing and modeling imply a simplification of complex ecological interactions. The benefit of that simplification is that conditions over very large areas can be studied without excessive labor costs.

Future research will focus on rangeland model parameter identification based on modern sensors (Landsat, MODIS), as well as other sources of remotely sensed and field data on the conditions of Kazakhstan's rangelands and local agroclimatic resources. We also expect to assess the possibility of impacts under climate change and modifications of atmospheric chemistry and carbon balance on rangelands. If current efforts with this approach are able to demonstrate feasibility, and funding is available, the approach will be expanded to a national effort to monitor rangelands across Kazakhstan.

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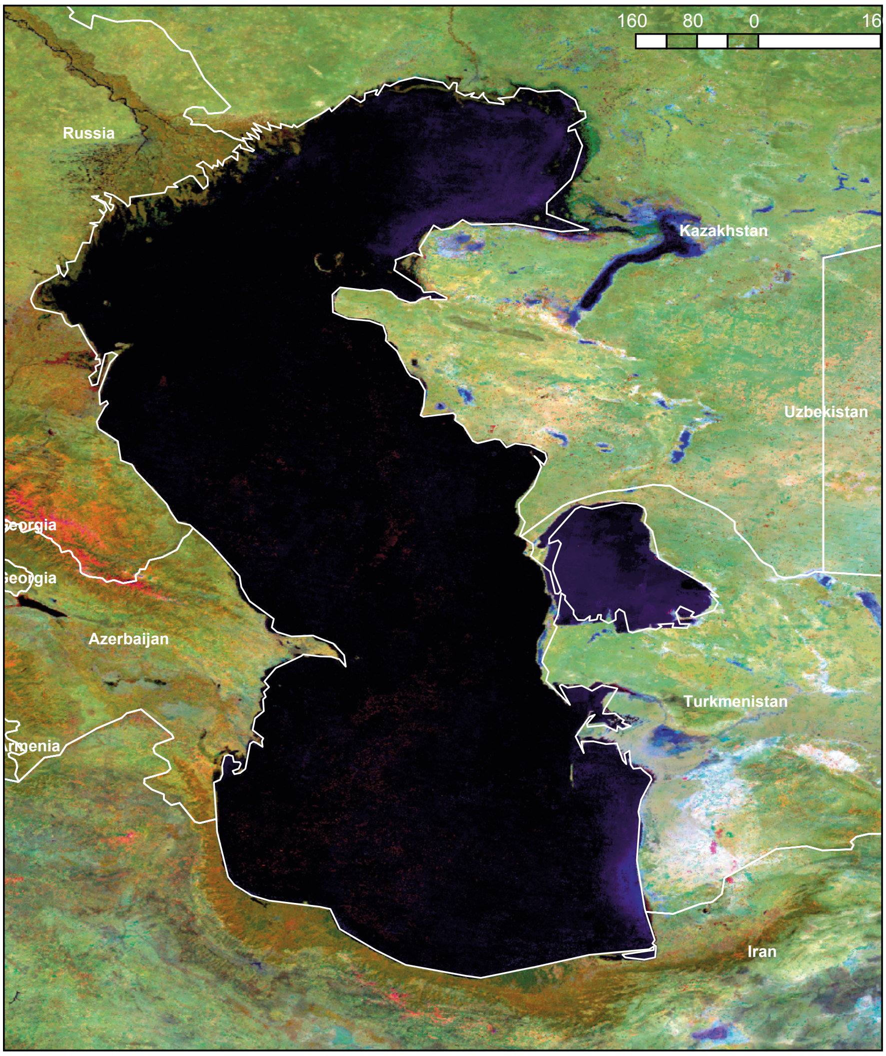
Part II

Regional Climate, Consequences and Adaptations



Caspian Sea seen from Terra Satellite (MODIS)

POSSIBLE CHANGES IN AGRICULTURE UNDER THE INFLUENCE OF CLIMATE CHANGE IN KAZAKHSTAN

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Abstract. This study deals with possible changes in agriculture under the influence of climate change and discusses the methods of adaptation in Kazakhstan.

Keywords: Global warming, spring wheat, soil protection system, pasture vegetation, digression, livestock breeding, food stock, breeding load, adaptation, driving-pasture system, phytomelioration

1. Introduction

The Republic of Kazakhstan is a country with developed agriculture branch of economy, which is represented by grain production and livestock breeding, among others. According to the agro-climatic zoning of Kazakhstan (Figure 1), crops are sown in semi-arid and arid steppe oblasts with varying temperatures, and in the foothills of the southern and south-eastern regions. Pasture livestock-breeding is developed in very dry, moderately hot semi-desert oblasts and in very dry, hot desert areas.

The Republic of Kazakhstan is among the world's six largest exporters of grain, mainly of spring wheat. In the Republic, spring wheat production was about 14 million tons, of which 4–5 million tons were exported annually during recent years. In 2007 the grain volume increased to 22 million tons, and the planned export was 10 million tons. This grain is exported to more than 40 countries including Russia, Tajikistan, Turkey, Azerbaijan and African

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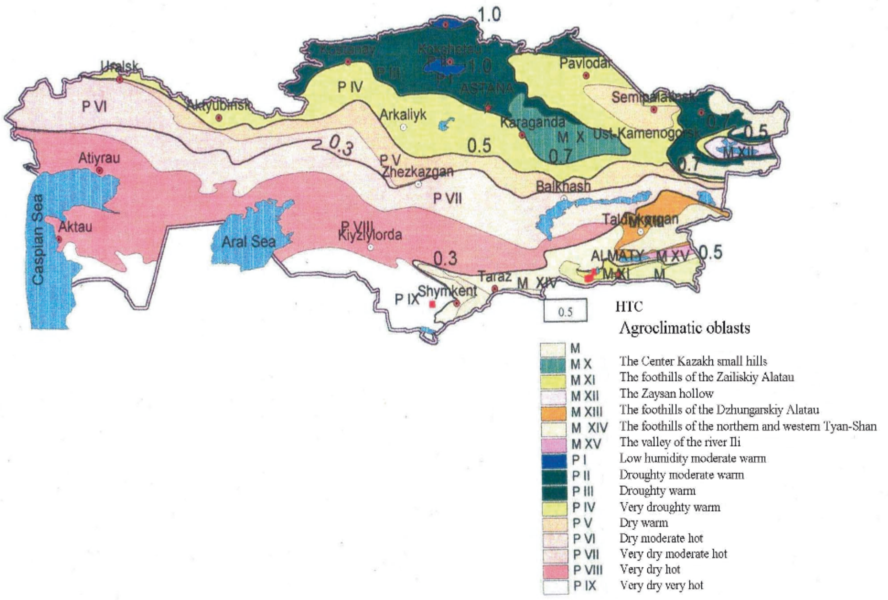

Figure 1. Agro-climatic zoning of the Kazakhstan area.

countries. UN experts concluded that in the long term Kazakhstan would be able to provide food for more than 100 million people. Spring wheat production is concentrated in Northern Kazakhstan and occupies about 10 million hectares. Climate conditions of Northern Kazakhstan allow the production of the high quality grain with gluten content of 30–33%. Winter wheat is grown mainly in the foothills of the mountains on 0.4 million hectares in southern and south-eastern regions of Kazakhstan.

Livestock production in Kazakhstan provides for 44% of the gross agricultural output and consists mainly of sheep breeding, beef and dairy cattle breeding, horse breeding, camel breeding, pig breeding and poultry farming. Table 1 shows the dynamics of economic parameters in the livestock breeding sector according to data from the Kazakhstan National Agency of Statistics.

Natural pastures provide the main forage stock for livestock-breeding industries in the hot, dry climate of Kazakhstan, where there are limited water resources. According to the Land Management Agency of Kazakhstan, the area of natural pastures in 2005 was about 189 million hectares (85% of all agricultural lands), and deserts and semi-deserts accounted for over 50% of that area.

In the desert, vegetation cover on pastures consists mainly of xerophytic and hallophytic bushes, semi-bushes and small shrubs. The fodder stock on desert pastures makes roughly up to 20 million tons of dry mass and up to 10 million tons of fodder units.

TABLE 1. Statistical indicators of the livestock-breeding sector in Kazakhstan.

Indicators	1990	2001	2002	2003	2004	2005
Animal quantity for all production categories: thousand heads:						
Cattle	9,757.2	4,106.6	4,293.5	4,559.5	4,871.0	5,203.9
Sheep	35,660.5	9,981.1	10,478.6	11,273.0	12,247.1	13,409.1
Horses	1,626.3	976.0	989.5	10,19.3	1,064.3	1,120.4
Camels	143.0	98.2	103.8	107.5	114.9	125.7
Livestock production:						
Meat, thousand tons:	1,559.6	654.5	672.6	693.2	737.1	762.2
Milk, thousand tons:	5,641.6	3,922.9	4,109.8	4,316.7	4,556.8	4,749.2
Wool thousand tons:	107.9	23.6	24.8	26.8	28.5	30.4
Growth per 100 head:						
Calves	81	77	83	82	80	78
Lambs	93	95	92	95	95	89

2. Influence of climate change on grain production

Global warming in the twentieth and twenty-first centuries and growth of aridity have had serious impacts on agriculture in Kazakhstan. Meteorological observations at network stations located in Kazakhstan show that annual air temperatures have increased by 1.57°C over the last 110 years, with the greatest growth observed in winter and early spring (Figure 2). The results

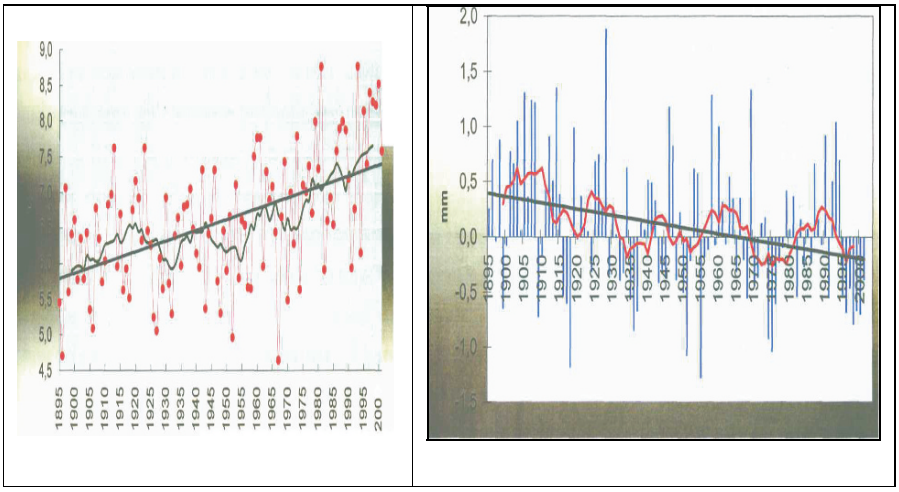

Figure 2. Air temperature (°C) and precipitation (mm) dynamics measured at meteorological stations in Kazakhstan (S. Dolgikh, 2004).

of regional climate modeling for Kazakhstan using modern models of climate variability suggest there will be further warming by 3–4°C and growth of aridity. Precipitation tends to be reduced in summer and increased in winter. Thus, future agro-meteorological conditions will be less conducive to spring wheat growth. Under these conditions, the role of soil moisture stocks in spring will increase, whereas the role of July precipitation maximum will become less important in meeting water needs for cultivation of spring wheat in Northern Kazakhstan.

An estimation of the impact of climate change on wheat sowing in Kazakhstan was calculated based on a local model designed by Lebed and Belenkova (1995) and the DSSAT model described by J. Ritchi and S. Otter (Table 2). Due directly to the negative effect of climate changes, growth of spring wheat could fall by 62–67% in Kazakhstan. These negative effects should, however, be mitigated to some extent by an expected increase in the atmospheric CO_2 concentration, for a total reduction of only 26–27%.

TABLE 2. Agro-climatic conditions and wheat yields under climate change scenarios in the Republic of Kazakhstan from the Kazakhstan – US project "Greenhouse gases and climate change in Kazakhstan" (1993–1996).

Agroclimatic model	Climate model	Climate scenarios		Agroclimatic conditions (Δ%)		Yield (Δ%)	
		Basis	Perspective	Warm	Moisture	Spring wheat	Winter wheat
1. **"Grain"**, Kazakhstan, L. Lebed and Z. Belenkova	GFDL-30	1951–1980	$2CO_2$	From –62 to –72	From –81 to –87	From –41 to –44	From –7 to –25
2. **CERES-Wheat (DSSAT)**, US, J. Ritchi and S. Otter	GFDL CCCM	1951–1980 1951–1980	$2CO_2$ $2CO_2$			From –26 to –27	From +35 to –100

The development of a soil protection system in Northern Kazakhstan is the foundation for grain production adaptation in conditions of climate change. This system is based on the soil-protective agriculture theory, which describes methods of protection against soil erosion and preservation of soil fertility and moisture (Kaskarbaev, 2003). Further improvement of soil-protective farming methods should be focused on the following measures:

- Minimization of soil tillage to preserve soil moisture and resources
- Selection of varied crop rotations, including grain and forage legumes
- Diversification of plant production, including more varieties in crop rotation oriented to different environment conditions

- Proper application of phosphoric and nitric fertilizers
- Improvement of snow retention by leaving high stubble when harvesting and sowing fallow fields
- Effective use of long-term weather forecasts to determine optimal sowing practices and crop selection

3. Influence of climate change on pasture vegetation

3.1. ESTIMATION OF PASTURE VEGETATION UNDER CLIMATE CHANGE

Unsystematic and unregulated use of natural pastures and hayfields in Kazakhstan was a major cause of pasture digression, which was observed in 60% of the pasture lands in the early 1990s. Over the last decade, not more than 30% of pasture lands have been used for grazing. This decrease is related to a sharp reduction in the population of both domestic and wild animals in the mid 1990s, destruction of wells and watering units for cattle, and concentration of grazing close to settlements, where separate wells and surface water sources remained (Levin, 2007).

Strongly marked fluctuations in the soil and vegetation cover of pasture lands in Kazakhstan were related to social and economic instability in the agricultural sector over the last decades. Climatic variability due to the greenhouse effect could further exacerbate these fluctuations.

Experts have made a tentative estimate of the future risks to the natural vegetation cover, as a natural fodder reserve, and the related livestock breeding risks under the impact of climate change. The estimation was based on the example of pastures in the Southern Balkhash area, located on the territory of Zhambylskiy and Ileyskiy administrative regions of Almaty oblast. According to agro-climatic zoning, the region is classified as “Very dry, hot” and “Very dry” (Figure 1).

The territory investigated in this study is made up primarily of eolic plain desert and foothill plain semi-desert, where sites with natural vegetation alternate with arable land under fodder grass crops of earlier years. It occupies an area of about 1.8 million hectares. Four meteorological operating stations, including Aul-4, Bakanas, Aydarly and Aksenger, provide data for this area.

Productivity of pastures on foothill plains, which are mainly used for grazing in spring and autumn, changes throughout the territory from 0.03 to 0.14 t/ha in spring and from 0.13 to 0.28 t/ha in autumn. Productivity of pastures on the sandy plain, which are used in winter, varies from 0.10 to 0.25 t/ha. In the early 1990s due to unbalanced grazing practices, pasture digression on sandy plains was weak to average, and on foothill plains it was average to strong.

The estimation of the impact of climate change on natural vegetation cover on pastures in the Southern Balkhash area was carried out for two time periods: 2030, 2050. Two different climate change scenarios, A_2 and B_2, were calculated by the IPCC. The scenarios presume different growth of greenhouse gas concentration in the atmosphere: climate scenario A_2 is based on the accelerated growth of GHG concentration; the B_2 climate scenario is characterized by a rather moderate concentration increase. Scenario A_2 is based on the approximate economic and social development of various states and regions, whereas B_2 includes more individual emission scenarios for each state.

Of the main greenhouse gases in the atmosphere, including carbon dioxide, methane and nitrogen oxide, possible changes in carbon dioxide concentration is of the greatest interest as it participates directly in photosynthesis and respiration in plants. According to the IPCC estimates under climate scenario A_2, CO_2 concentration in the atmosphere presumably will reach 540 parts per billion by 2050, i.e., will increase approximately 1.5 times in comparison with the base 1990 level. Under the B_2 climate scenario, CO_2 concentration in the atmosphere is expected to reach 480 billion^{-1} by 2085, thus it will increase only 1.4 times.

On the basis of the future climate scenarios in Kazakhstan constructed with the help of five equilibrium ocean-atmosphere models CERF 98, CS 1296, ECH498, CSM 98, and HAD300, experts calculated possible changes in average monthly air temperature (°C) and atmospheric precipitation (%) in comparison with their base levels for 1961–2000 (Tables 3 and 4).

TABLE 3. Dynamics of possible air temperature changes (°C) in the Southern Balkhash area.

Mean values according to climate models CRFTR 98, CS12TR 96, CSMTR 98, ECH4TR 98, HAD3TR 00.

Scenario	January	February	March	April	May	June	July	August	September	October	November	December
A_2 – 2030	1.4	1.5	1.6	1.5	1.5	1.1	1.1	1.4	1.4	1.3	0.5	0.8
A_2 – 2050	2.7	2.8	2.8	2.6	2.7	2.4	2.3	2.7	2.6	2.3	1.4	1.6
A_2 – 2085	5.8	5.5	5.4	4.6	5.1	6.0	5.4	5.4	5.2	4.2	3.8	3.8
B_2 – 2030	2.1	1.7	1.5	1.3	1.6	1.9	1.8	1.8	1.8	1.5	1.5	1.4
B_2 – 2050	2.6	2.7	2.3	2.0	2.5	3.1	3.1	2.7	2.8	2.2	2.3	2.1
B_2 – 2085	4.9	4.2	3.8	3.3	4.0	4.9	4.5	4.3	4.4	3.5	3.6	3.3

TABLE 4. Possible precipitation change (%) in the Southern Balkhash area. Mean values according to climate models CRFTR 98, CS12TR 96, CSMTR 98, ECH4TR 98, HAD3TR 00.

Scenario	January	February	March	April	May	June	July	August	September	October	November	December	Annual
A_2 – 2030	9	15	5	5	-4	-9	30	54	6	4	12	13	2
A_2 – 2050	15	23	10	4	-3	-13	27	52	1	4	15	17	3
A_2 – 2085	35	39	20	7	4	-17	-15	-1	-30	0	14	19	6
B_2 – 2030	3	10	5	3	-1	-2	-20	7	-14	9	4	9	3
B_2 – 2050	16	19	8	4	0.3	-4	-10	1	-21	10	4	11	4
B_2 – 2085	26	25	14	6	2	-7	-8	8	-31	11	6	23	6

As Table 3 shows, changes in air temperature in the Southern Balkhash area during the first half of the twenty-first century can be more significant under the B_2 climate scenario than the A_2 scenario. According to B_2, air temperatures will increase by a maximum of over 2°C in 2030 and over 3°C in 2050. Table 4 presents the dynamics of atmospheric precipitation, which is expected to increase by up to 6% annually, an insignificant amount, under both climate scenarios. Seasonal trends show a shift of precipitation from warm to cold seasons, which is more pronounced under scenario A_2. Considering the possible direct influence of the increased air temperature and other changed climate parameters on vegetation, it is necessary to note that comprehensive estimation of possible changes in vegetation cover should include also the positive impact of the increased GHG concentration in the atmosphere.

Often these impacts have opposite signs that make it necessary to use pasture efficiency models with meteorological and CO_2 blocks. In order to estimate possible vulnerability of pastures under temperature rise and simultaneous increase in atmospheric CO_2 concentration, the author updated an earlier “Pasture” model based on the theory of production processes in plants (Lebed and Belenkova, 1995; Lebed, 2006).

3.2. ASSESSMENT OF POSSIBLE RISKS OF PASTURE PRESERVATION

Experts developed the environmental, social and economic scenarios of the present day initial condition of pastures in order to objectively assess the future risks for pasture preservation and to suggest possible means of adaptation to climate change (Table 5, Attachment). Considering the practice of livestock grazing, the present condition of pastures in Kazakhstan is the result of:

- The driving-pasture system of grazing and seasonal pasturing implemented from the mid-1970s to the late-1990s and
- Unregulated use of pastures during the last decade due to incomplete state reforms of agricultural land management

Analysis of the economic parameters of livestock breeding development in Kazakhstan (Table 1) and the environmental-economic condition of pasture lands (Table 5) shows that economic instability of livestock breeding is constantly accompanied by ecological instability of natural ecosystems (pastures).

Environmental and estimation of possible adaptation we shall present by: Using average seasonal pasture productivity (ton of dry mass on hectare), seasonal fodder stocks (fodder units per hectare), and safe loads of sheep on pastures (head per 100 ha), we estimate the environmental and economic parameters of possible changes in natural pastures under expected climate changes. We then suggest possible adaptation scenarios. The anthropogenic impact on pastures is expressed in varying degrees of pasture digression from weak to strong.

Due to the uncertainty of future global development, it is more realistic to focus on short term rather than long term analysis. As climate scenarios A_2 and B_2 show similar results, in the next 10 years we shall use B_2 scenario for the further strategy development concerning climate change impacts and adaptation of pastures in the Southern Balkhash in order to better protect the environment and ensure local and regional stability.

For modeling pasture productivity, experts used meteorological information from 1976–2005. To parameterize the Pasture model, experts incorporated retro-data from air spectrometer observations of pastures in the Balkhash area made by «KazNIIEK» expeditions in 1986–1990. These data reflect the vegetation conditions under remote pasturing.

Fodder stocks on pastures were estimated in view of seasonal consumption of plants and their fodder value. Livestock (sheep) loads on pastures are presented according to forage needs – 2 kg of fodder units a day per head under vegetation detachment of 60%.

Calculations of possible dynamics in environmental and economic parameters of pastures in the Southern Balkhash area under climate change for 2030 and 2050 are presented in Tables 6 and 7 (*Legend: Sp – Spring,* *Su-Summer, Au-Autumn, Wn-Winter; 0.10* - Halloxilon not calculated; A. Balkhashskiy; B. Zhambylskiy; C. Kurtynskiy; D. Ikeyskiy; 1. Shrubbery-Artemisia –Halophytics on hilly sand of desert plain; 2. Artemisia-Ephemeri –Halophytic on serozem soil of semi-desert plain*), depending on their initial ecological condition. Tables show that for sandy plain pastures, productivity can decrease as air temperature rises in all seasons. For pastures on foothill plains, which have a lot of ephemeral plants, productivity can increase significantly in spring and summer-autumn as air temperature rises. Risks to pasture safety under climate variability can be estimated in loss (increase) of fodder units per area. As Tables 6 and 7 show, under further warming in the Southern Balkhash area, the fodder stocks on semi-desert pastures of foothill plains with average to strong digression degrees can increase significantly in spring and early summer. This is especially evident in places where the vegetation is less battered and maintains its regenerative functions. Productivity of these plants can increase to a smaller extent in summer and autumn. In cases of significant digression of foothill pastures in the Southern Balkhash area, which occurred during last decade because of excessive year-round grazing, the fodder stocks can increase by 2030.

On the desert pastures of the sandy plain, under raised air temperatures, the change in fodder stocks can be less significant on pastures with degradation levels from weak to average. The greatest losses of fodder units can occur in spring 2030 and summer-autumn 2050. In winter, when grazing is heaviest on these pastures, fodder stocks can decrease slightly. It is possible to assume that for present pastures on the sandy plain under light or no grazing, the losses of fodder units can be even smaller, at least for 2030.

According to Tables 6 and 7, possible changes in the safe sheep loads can be more significant for semi-desert pastures of foothill plains with an increase of 55–122 sheep per 100 ha in spring and 57–118 annually. On pastures of desert the sandy plain the annual animal loading can decrease by 20 head in 2030 and by 25 head per 100 ha in 2085, with a slight increase in spring during the second half of this century.

3.3. ASSESSMENT OF POSSIBLE ADAPTATION MEASURES

Taking into account Kazakhstan's prior experience with natural pasture restoration under dry and unstable climate conditions, it is possible to recommend measures that would create more pasture areas and adapt pastures to climate variability. These include:

- Completion of state land reforms and legal assignment of pasture lands to users
- Provision of several types of pastures for every individual user or rural community for grazing in different seasons

- Development of remote pastures with partially restored vegetation, including restoration of facilities and water resources on these pastures
- Regulation of livestock loading on pastures, including mandatory seasonal pasture rotation and reductions in livestock loads near settlements where pastures are strongly digressed
- Manufacture of rough forage missing in the animals' diet through restoration of long-term grass crops on arable lands and preservation of the productive life of available hayfields

The problem of water supply on pastures in the Southern Balkhash area should be solved with the help of underground water. Accessing underground water resources requires restoration of wells and installation of water-lifts with independent energy sources.

In order to restore and protect the future safety of vegetation on desert pastures of plains and semi-desert pastures of foothill plains under the present climate and future changes, it is necessary to establish and maintain safe cattle loads as presented in Tables 6 and 7. Taking into account the partial restoration of pasture vegetation during the last decades, it is possible to increase the loading norm slightly in winter and to prolong the cattle grazing period in spring on the sandy plain. Due to excessive regression on pastures of foothill plains, cattle loads in spring and autumn can be reduced a little in comparison with the calculated values from Tables 6 and 7.

To reduce risks to the safety of semi-desert pastures on foothill plains, it is possible to implement measures developed earlier at the Research and Production Center for Livestock Breeding and Veterinary Science under the Ministry of Agriculture of Kazakhstan (Zhambakin, 1972). These measures include sowing crops and natural plants in order to promote phytomelioration of pasture lands and paddocks.

4. Conclusion

Adaptation of agriculture to the adverse conditions of both present and future climate in Kazakhstan can be solved successfully within existing state target programs, such as the State Agricultural and Food Program of the Republic of Kazakhstan for 2003–2005 and following years, as well as the State Program of Rural Area Development of the Republic of Kazakhstan for 2004–2015, among others. The solution of ecological stability problems of pasture lands is included in the operating Program of the Republic of Kazakhstan on Combating Desertification for 2007–2017. These tasks are also fixed in the Concept of Ecological Safety of the Republic of Kazakhstan for 2004–2015, which has the goal of preserving biodiversity and preventing desertification and degradation of pasture lands. The main focus of solutions for these problems is improvement of economic mechanisms of natural resource management combined with regular ecological monitoring.

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ATTACHMENT

TABLE 5. Socio-economical and ecological scenarios of pasture stock-breeding conditions in Southern Kazakhstan.

Years	Property and land use forms	Pasture use peculiarities	Pasture load	Climate influence	Bio-ecological state of pasture plants
1961–1993	State property using sovchos and colchos.	Driving-pasture systems by multi-season change of grazing and transfer of sheep over long distances. Sufficient wells and watering for animals. Food shortage on autumn and spring pastures.	Moderate on sandy pastures and excessive on foothills of mountain plains and mountain valleys.	Lack of soil moisture for plants, soil salinization and wind erosion. Cold weather and high show in winter and hot weather in summer for grazing of animals.	Low and unstable yields, elementary and middle of pasture digression categories.
1994–2006	State property agriculture enterprises, firms and long-term land rent. Private property.	Non-system pasturage near villages and wells. Insufficient use of distant pastures. Lack of watering places and wells for animals on pastures.	Excessive and uneven on near pastures and lacking in remote pastures.		Highest degradation category of vegetative cover on near pastures. Restoration of vegetation cover on distant pastures. Biodiversity is decreasing.

TABLE 6. Possible pasture yield, food volume and sheep loads under climate change scenario B_2 in Southern Balkhash modeled for 2030 based on 1990.

Regions in 1990	Pasture type	Digression category	Seasons of use	Year	Yield (tons/ha)				Food volume (food units/ha)				Sheep load (sheep/100 ha)			
					Spring	Summer	Autumn	Winter	Sp.	Su.	Au.	W.	Sp.	Su.	Au.	W.
A	1	Average-weak	Winter	1990	0.10*	0.38*	0.33*	0.17	40	114	82	34	40	28	60	11
				2030	0.10*	0.27*	0.22*	0.12*	40	80	55	25	46	16	40	9
				Δ	**0**	**-0.11**	**-0.11**	**-0.05**	**0**	**-34**	**-27**	**-9**	**+6**	**-12**	**-20**	**-2**
B	1	Average	Winter	1990	0.12	0.35	0.30	0.16	56	126	100	58	56	31	73	19
				2030	0.11	0.32	0.25	0.14	49	115	82	50	58	23	60	17
				Δ	**-0.01**	**-0.03**	**-0.05**	**-0.02**	**-7**	**-11**	**-18**	**-8**	**+2**	**-8**	**-13**	**-2**
	2	Strong	Spring	1990	0.16	0.22	0.18	0.13	80	73	18	–	80	18	18	–
			and	2030	0.26	0.25	0.20	0.15	130	82	15	–	146	17	20	–
			autumn	Δ	**+0.10**	**+0.03**	**+0.02**	**-0.02**	**+50**	**+9**	**-3**	–	**+66**	**-1**	**-2**	–
C	1	Average-weak	Winter	1990	0.29	0.41	0.34	0.18	125	123	85	38	125	30	62	8
				2030	0.14	0.43	0.41	0.19	62	129	102	40	71	26	74	8
				Δ	**-0.15**	**+0.02**	**+0.07**	**+0.01**	**-63**	**+6**	**+17**	**+2**	**-54**	**-4**	**+12**	**0**
	2	Strong	Spring	1990	0.14	0.27	0.18	0.17	70	95	45	–	70	23	32	–
			and	2030	0.16	0.25	0.20	0.15	80	88	50	–	92	18	36	–
			autumn	**Δ**	**+0.02**	**-0.02**	**+0.02**	**+0.02**	**+10**	**-7**	**+5**	–	**+22**	**-5**	**+4**	–
D	1	Average-weak	Winter	1990	0.24	0.59	0.41	0.26	100	148	66	42	100	36	49	8
				2030	0.26	0.54	0.44	0.24	106	135	70	38	123	27	51	8
				Δ	**+0.02**	**-0.05**	**+0.03**	**-0.02**	**+6**	**-13**	**+4**	**-4**	**+23**	**-9**	**+2**	**0**
	2	Strong	Spring	1990	0.13	0.31	0.20	0.19	52	110	40	–	52	28	29	–
			and	2030	0.28	0.44	0.28	0.26	112	158	50	–	129	32	36	–
			autumn	**Δ**	**+0.15**	**+0.13**	**+0.08**	**+0.07**	**+60**	**+48**	**+10**	**–-**	**+77**	**+4**	**+7**	–

0.10* – Halloxilon not calculated; A. Balkhashskiy; B. Zhambylskiy; C. Kurtynskiy; D. Ikeyskiy.

TABLE 7. Possible pasture yield, food volume and sheep loads under climate change scenario B_2 in Southern Balkhash modeled for 2050 based on 1990.

Regions in 1990	Pasture type	Digress-ion category	Seasons of use	Year	Yield (t/ha)				Food volume (food units/ha)				Sheep load (sheep/100 ha)			
					Spring	Summer	Autumn	Winter	Sp.	Su.	Au.	W.	Sp.	Su.	Au.	W.
A	1	Average -	Winter	1990	0.10*	0.38*	0.33*	0.17*	40	114	82	34	40	28	60	11
		weak		2050	0.26*	0.27*	0.19*	0.12*	104	81	48	25	138	16	35	9
				Δ	**+0.16**	**-0.11**	**-0.14**	**-0.05**	**+64**	**-33**	**-34**	**-9**	**+98**	**-12**	**-25**	**-2**
B	1	Average	Winter	1990	0.12	0.35	0.30	0.16	56	126	100	58	56	31	73	19
				2050	0.14	0.31	0.24	0.14	54	112	79	50	71	22	82	17
				Δ	**-0.02**	**-0.04**	**-0.06**	**-0.02**	**-2**	**-14**	**-21**	**-8**	**+15**	**-9**	**-11**	**-2**
	2	Strong	Spring	1990	0.16	0.22	0.18	0.13	80	73	18	–	80	18	18	–
			and	2050	0.31	0.26	0.20	0.16	155	86	39	–	206	17	20	–
			autumn	**Δ**	**+0.15**	**+0.04**	**+0.02**	**+0.03**	**+75**	**+13**	**+21**	–	**+126**	**-1**	**-2**	–
C	1	Average-	Winter	1990	0.29	0.41	0.34	0.18	125	123	85	38	125	30	62	8
		weak		2050	0.16	0.33	0.27	0.15	69	100	68	31	91	20	50	7
				Δ	**-0.13**	**-0.08**	**-0.07**	**-0.03**	**-56**	**-23**	**-17**	**-7**	**-34**	**-10**	**-12**	**-1**
	2	Strong	Spring	1990	0.14	0.27	0.18	0.17	70	95	45	–	70	23	32	–
			and	2050	0.27	0.22	0.17	0.13	138	77	42	–	180	15	30	–
			autumn	**Δ**	**+0.13**	**-0.05**	**0.01**	**-0.04**	**+65**	**-18**	**-3**	–	**+50**	**-8**	**-2**	–
D	1	Average-	Winter	1990	0.24	0.59	0.41	0.26	100	148	66	42	100	36	49	8
		weak		2050	0.30	0.54	0.46	0.24	120	135	76	38	160	27	50	8
				Δ	**+0.06**	**-0.05**	**+0.05**	**-0.02**	**+20**	**-13**	**+10**	**-4**	**+60**	**-9**	**+1**	**0**
	2	Strong	Spring	1990	0.13	0.31	0.20	0.19	52	110	40	–	52	28	29	–
			and	2050	0.32	0.37	0.24	0.22	128	133	43	–	171	26	32	–
			autumn	**Δ**	**+0.19**	**+0.06**	**+0.04**	**-0.03**	**+76**	**+23**	**+3**	–	**+119**	**-2**	**+3**	–

CONSTRUCTING MODEL-BASED CLIMATE CHANGE SCENARIOS FOR SOUTHEASTERN KAZAKHSTAN AND THE POSSIBILITIES FOR IMPACT ASSESSMENT

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Abstract. This chapter describes a methodological approach to be used in developing regional climate change scenarios for southeastern Kazakhstan. It also addresses possibilities for using these scenarios in impact assessments in various economic and natural resource sectors. The regional scenarios are based on the output data of the global climate models and their interpretation at a case site in the Lake Balkhash basin.

Keywords: Climate change scenarios, air surface temperature, precipitation, global climate models

1. Introduction

This study seeks to construct climate change scenarios for the region of Lake Balkhash basin, which is located in the arid and semi-arid zones of Kazakhstan. Regional climate change scenarios further may be used for assessment of possible changes in agro-climatic conditions and parameters of vegetation cover under the potential climate change impacts.

The technical approach used in this study is a methodology that is accepted by a number of foreign climatic research centers, which have developed global climate models (GCM) (Climate Changes in Belarus and Their Consequences, 2003). The current climate changes in Kazakhstan occur on a background of global climate changes that are also influenced by anthropogenic impacts. Regional climate scenarios are constructed on the

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basis of global climate models, allowing calculating climatic system conditions depending on the growth of greenhouse gas concentrations in the atmosphere, which is considered to be a major factor of the future climate changes. Regional interpretation of the output data obtained by modeling experiments with GCM at the various levels of CO_2 concentration enables us to compare current and expected climate conditions. Regional climate change scenarios will be constructed on the basis of modeled data of the future climatic conditions prepared by groups of scientists under the Intergovernmental Panel of Climate Change (IPCC). Global climate change scenarios were obtained from the IPCC Data Distribution Center (DDC) (Full Report Working Group I, 2007) which is specially created for the support of researches in the field of climate change vulnerability and adaptation assessments.

2. Climate change tendencies in Kazakhstan in the twentieth and twenty-first centuries

The previous studies of the current tendencies in temperature time series have shown that general temperature growth has taken place during the last century in Kazakhstan (First National Communication, 1998). Compared to temperature data for the whole period of instrumental observations of the meteorological network of Kazakhstan (mainly started operating since the year 1881), the last 15 years were extremely warm. The positive tendency during average annual temperatures was stable. In connection with the general global warming a sharp increase of intra-annual (seasonal) and inter-annual fluctuations of temperature and atmospheric precipitation in Kazakhstan is observed. Taking into account, that a significant part of the territory of Kazakhstan are deserts and semi-deserts, ecosystems and many sectors of economy of Kazakhstan, in particular, agriculture and water resources, are especially vulnerable to observed anomalies of climatic characteristics. Climate change, which is expressed as an increase in dryness at the general background of air temperature growth, can negatively affect conditions of grassland vegetation, which is a basis of forage reserve for livestock and sheep breading in Kazakhstan. The degree of pasture vulnerability in arid and semi-arid regions of Kazakhstan to negative impacts of expected climate changes will be estimated with the using of climate change scenarios which are developed for the given task.

The results of the previous studies of air temperature trends according to observational data on meteorological stations have shown, that for the last 50 years the annual mean temperatures in Kazakhstan have increased by 1.3–1.5°C (Bultekov et al., 2006). As Kazakhstan has a great extent from the North to the South and from the West to the East, it is necessary to note, that the increase in air temperature for the territory of Kazakhstan differs irregularly. The highest growth of annual mean temperatures (by 2.0–2.5°C) was observed in the East (Pavlodar, Semipalatinsk) and in the South of Kazakhstan (Kyzylorda). Only in the South-West (Aktau) the trend of air temperature was lower and equaled to 0.7°C, that, probably, is connected with the cooling influence of the Caspian Sea. Some temperature trends are illustrated on Figure 1 (Bultekov et al., 2006).

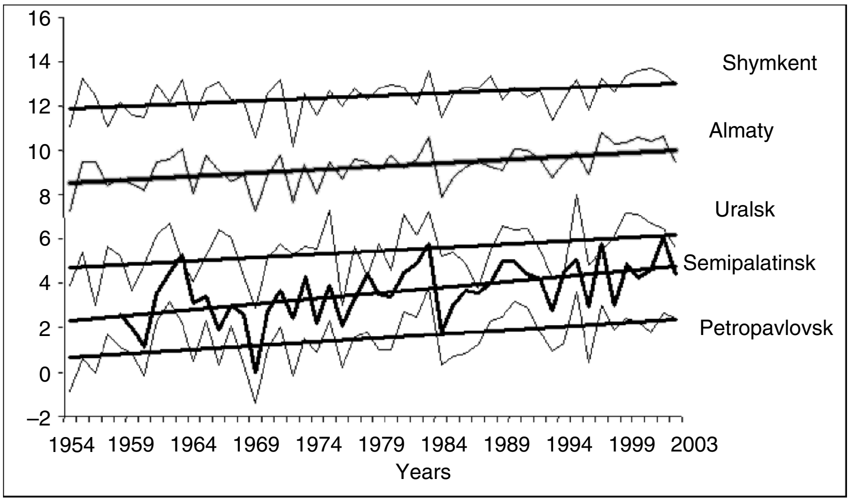

Figure 1. Mean annual temperature trends for some meteorological stations in Kazakhstan, degrees C.

Under global climate change, the majority of territories in Central Asia also have positive temperature trends. The Fourth Assessment Report of IPCC 2007 presents a probable climate changes which were received on the basis of climate simulations with GCM. This report indicates that the waves of heat and the periods with relatively high temperatures in Central Asia are getting longer, more intensive and frequent. The quantity of cold days will decrease. Thus the sums of atmospheric precipitation on a plain part of the territory can be reduced considerably.

Findings from multi-model scenario studies (which represent averaged scenario on several model scenarios) show that the level of annual mean temperatures in Central Asia can increase by 3.7°C by the end of the twenty-first century. The seasonal variation in the simulated warming is modest. The higher temperature increase over high-altitude area can be explained by the decrease in surface albedo, associated with an earlier melting of snow and ice. It is especially visible during winter months; however, because of a complex relief it does not look homogeneous.

Precipitation in Central Asia increases in winter, but decreases in the other seasons according to multi-model scenarios. On average by the end of twenty-first century the annual mean sums of precipitation is less by 3%, and from December till February they will increase almost by 4% while during a summer season (June–August) a significant decrease is observed (-13%). At the same time seasonal variations of atmospheric precipitation in Central Asia and Kazakhstan will be substantial.

For the development of regional climate change scenarios based on output data of GCM fields of climatic characteristics presented in the form of maps it is possible to choose data for the separate countries and regions. Thus, it is possible to construct climate change scenarios for the regions of the research in the grid points or by interpolation of these data into the meteorological stations.

For climate change scenarios constructions for arid and semi-arid zones of Kazakhstan the output climate data have been analyzed under increased concentrations of greenhouse gases in the global atmosphere for the period till 2100. Last output model data have been obtained for SRES emission scenarios (Special Report on Emission Scenarios) which count the basic climatic characteristics presented in (Full Report Working Group I, 2007) (Table 1).

3. Regional climate change scenarios for South-Eastern Kazakhstan

Climate change scenarios for the studied region have been constructed for average monthly mean air temperatures and sums of atmospheric precipitation for the three time intervals adhered to the middle of the following decades: 2010–2039, 2040–2069 and 2070–2099, accordingly, or for the years 2025, 2055 and 2085, appropriately for all months of the year. It is supposed, that if models well reproduce basic climate conditions they will also reproduce future climate most adequately. On this basis, three models have been chosen from the considered six models that describe the current climate in a proper way. These are the following models: ECHAM, CSIRO, and HadCM.

Within the limits of the studied region, the network of meteorological stations presented in Figure 2 was chosen. For these stations, changes of air temperature and precipitation values were obtained for the years 2025, 2055 and 2085 on the basis of model output data (Full Report Working Group I, 2007). The scenarios' data are presented in tables in the form of deviations from the norms (averaged climate data for the period between the years 1961 and 1990).

To construct climate change scenarios, the fields of climatic parameters in the visualized form were used (Full Report Working Group I, 2007). The example of similar scenarios is presented in Figures 3–5 for CSIRO/A2a scenario.

TABLE 1. Climatic output characteristics from the global climate models for scenarios constructions (Full Report Working Group, 2007).

Model	Version of the model	Climate parameters							
		TEMP[a]	TMAX[b]	TMIN[c]	PREC[d]	RHUM[e]	TCLW[f]	WIND[g]	SMOI[h]
CCC[i]	ma/A2a	*	*	*	*			*	
CCC	Ma/B2a	*	*	*	*			*	
CSIRO[j]	/A1a	*	*	*	*			*	
CSIRO	/A2a	*	*	*	*			*	
CSIRO	/B1a	*	*	*	*			*	
CSIRO	/B2a	*	*	*	*			*	
ECHAM[k]	4/A2a	*			*			*	
ECHAM	4/b2a	*			*			*	
GFDL[l]	99/A2a	*			*				
GFDL	99/B2a	*			*				
HadCM[m]	3/A1F	*	*	*	*	*	*	*	
HadCM	3/A2a	*	*	*	*	*		*	*
HadCM	3/A2b	*	*	*	*	*	*	*	
HadCM	3/A2c	*	*	*	*	*	*	*	
HadCM	3/B1a	*	*	*	*	*	*	*	
HadCM	3/B2a	*	*	*	*	*		*	*
HadCM	3/B2b	*	*	*	*	*	*	*	
NIES[n]	99/A1a	*	*	*	*			*	
NIES	99/A1F	*	*	*	*			*	
NIES	99/A1T	*	*	*	*			*	
NIES	99/A2a	*	*	*	*			*	
NIES	99/B1a	*	*	*	*			*	
NIES	99/B2a	*	*	*	*			*	

Designations:

[a]Average monthly temperature of air (K)

[b]Average maximal temperature of air (K)

[c]Average minimal temperature of air (K)

[d]The sums of deposits (mm/day)

[e]Relative humidity of air (%)

[f]Total solar radiation (Watt/m^2)

[g]Average scalar speed of a wind (m/s)

[h]Humidity of ground (mm)

[i]CCC – Model of the Canadian Center of Climate Modeling, Canada

[j]CSIRO – Model of the Scientific-Industrial Research Organization, Australia

[k]ECHAM – Model of Meteorological Institute by Max Planck, Germany

[l]GFDL – Model of Geophysics and Hydrodynamics Laboratory, USA

[m]HadCM – Model the Hadley Center of Climatic Forecasts and Researches, Great Britain

[n]NIES – Model of National Institute of Environmental Researches, Japan

The scenarios data can be presented in tables in the form of deviations from the norms (averaged climate data for the period between the years 1961 and 1990) (Climate Reference Book of Kazakhstan, 2004).

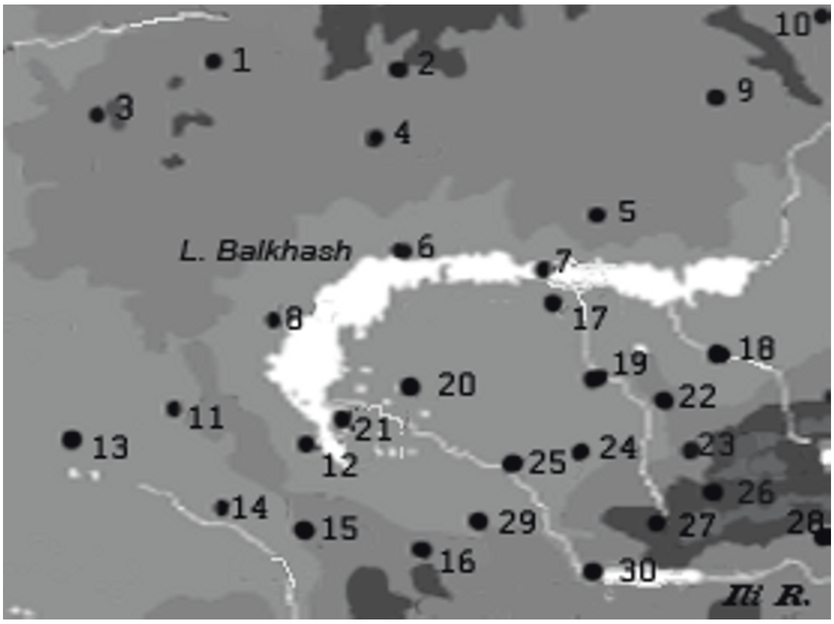

Figure 2. Meteorological network in Balkhash Basin.

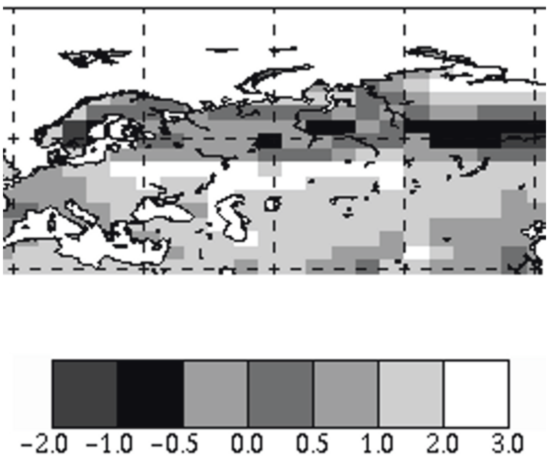

Figure 3. Air temperature changes in comparison with climatic norms. for July of the year 2025.

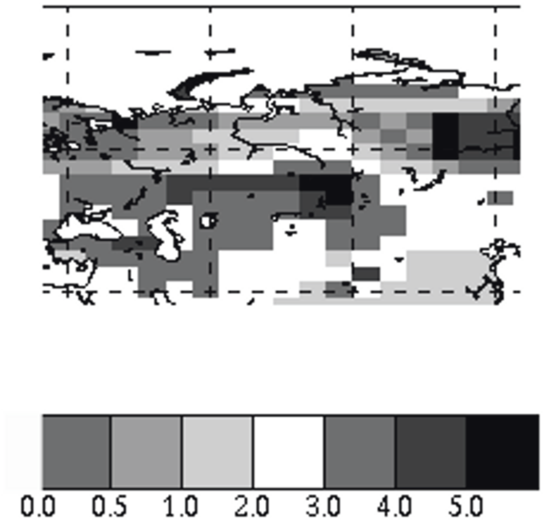

Figure 4. Air temperature changes in comparison with climatic norms for July of the year 2055.

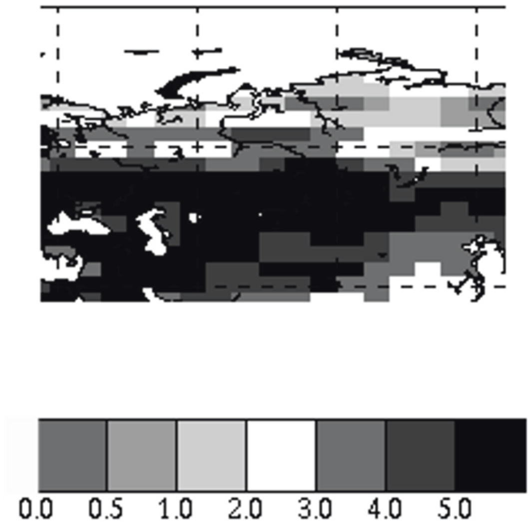

Figure 5. Air temperature changes in comparison with climatic norms for July of the year 2085.

Climate change scenarios are obtained as deviations from climatic norms on stations in table form for stations. As an example, air temperature scenarios are presented in Table 2.

TABLE 2. Air temperature change scenarios (according to CSIRO/A2a model scenario.

№ п/п	Name of the station	Mean monthly temperature in July (norm)	ΔT, July, 2025 (ºC)	ΔT, July, 2055 (ºC)	ΔT, July, 2055 (ºC)
1.	Agadyr	21.0	1.5	3.5	5.5
2.	Aktogai	19.8	1.5	3.5	5.5
3.	Kzyltu	20.1	1.5	3.5	5.5
4.	Bektauata	23.0	1.5	3.5	5.5
5.	Sayak	24.9	1.5	3.0	5.5
6.	Balkhash	24.2	1.5	3.0	5.5
7.	Algazy Island	24.9	1.5	3.0	5.5
8.	Saryshagan	24.9	1.5	3.0	5.5
9.	Barshatas	21.4	1.5	3.0	5.5
10.	Ayaguz	20.8	1.5	3.2	5.5
11.	Tuyken	25.6	1.5	3.5	5.5
12.	Chiganak	25.8	1.5	3.0	5.5
13.	Ulanbel	26.7	1.5	3.5	5.5
14.	Moyinkum	25.2	1.5	3.3	5.5
15.	Hantau	27.2	1.5	3.0	5.5
16.	Anarhai	25.6	1.5	3.0	5.5
17.	Ucharal	24.3	1.5	2.8	5.5
18.	Matai	25.0	1.5	2.8	5.5
19.	Naimansuyek	24.5	1.5	2.8	5.5
20.	Aul №4	25.0	1.5	2.8	5.5
21.	Kuigan	24.9	1.5	3.0	5.5
22.	Ushtobe	23.9	1.5	2.8	5.5
23.	Taldykorgan	23.6	1.5	2.6	5.5
24.	Zhetyzhol	25.3	1.5	2.6	5.5
25.	Bakanas	25.8	1.5	2.5	5.5
26.	Kugaly	17.0	1.5	2.5	5.5
27.	Saryozek	22.2	1.5	2.5	5.5
28.	Zharkent	24.0	1.5	2.5	5.5
29.	Aidarly	26.0	1.5	2.6	5.5
30.	Kapchagai	25.5	1.5	2.6	5.5

The results of climate change scenarios show that temperature is expected to increase from 1.5 to 5.5°C with time in the studied region. Temperature rise may lead to negative consequences for climate conditions and enhance conditions of aridity.

On the basis of these regional scenarios and the associated changes of climate characteristics, it is possible to estimate possible consequences of regional climate change in Kazakhstan. Using these data, further impact assessments can be carried out for changes of climatic and agro-climatic indices (humidity factors, indices of dryness, potential evapotranspiration, etc.). Besides regional climate change, scenarios can be used as input data for forecast modeling of different agricultural and agroclimatic characteristics (wheat yield, grassland productivity), which are expected in Kazakhstan under anthropogenic climate change. They may also be used in hydrological and hydro-technical calculations of water balance and runoff changes.

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Rangeland in Kazakhstan.

CLIMATE CHANGE AND POSSIBLE CHANGES IN THE WATER REGIME OF CROPS IN NORTHERN KAZAKHSTAN

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Abstract. This chapter presents results from assessments of evapotranspiration from agricultural fields and possible changes in connection with climate change in the context of Northern Kazakhstan – the main region of spring wheat sowings in the Republic of Kazakhstan. In calculations of evapotranspiration, the Penman-Monteith modern method was employed, as advised by the Food and Agriculture Organization of the United Nations (FAO) for these purposes.

Keywords: Climate change, water regime, crops, evapotranspiration, soil droughts, Northern Kazakhstan

1. Introduction

In recent years food safety has become an important policy topic in many countries because of global warming. The Republic of Kazakhstan is not an exception since the basic physical availability of food is provided on consumption minimum level. After the collapse of the Soviet Union agriculture land management policies in Kazakhstan were reformed, and a large number of managing subjects with private ownership has appeared. Now in Kazakhstan small-scale grain farming dominates (about 56%). Such production disadvantages are: a low level of technology, labor inefficiencies, and a large, relatively poor rural population. Though last year's agricultural development in the republic was characterized by positive dynamics, GDP

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per 1 rural dweller was still 1.8 times lower than in Russia, 7.5 times lower than in Germany and South Korea, and 43 times lower than in Belgium (Gosudarstvennaya, 2003).

Crops are the main component of food safety in Kazakhstan. The republic has sufficient land and natural resources for grain production to supply grain not only to Kazakhstan, but also to neighboring states. Spring wheat is important for the republic because it is a highly competitive good in the world market and is exported to more than 40 countries. It makes up more than 71.3% of the total structure of the nation's crop sowings. The arid climate of Northern Kazakhstan is most favorable for production of spring wheat. The protein content and flour quality of the spring wheat cultivated there considerably exceeds that of the wheat cultivated in other countries.

At the same time, grain production in Northern Kazakhstan has an unstable nature because the fields are situated in a risky agriculture zone. In this region the bioclimatic potential of arable lands is in 2.5 times lower than in Western Europe, and the spring wheat yield is one of the lowest in the world. It was about 0.99 t/ha for 2000–2006. About the 60–70% of the total production risk in Kazakhstan grain production is connected with weather and climate dynamic (Agrometeorological and Agroecological Information, 2006).

2. The modern assessment of crop water regime in Northern Kazakhstan

In the arid conditions of Northern Kazakhstan, the major factor limiting crops is moisture. Earlier obtained researches results of the agro-meteorological condition assessment of the crop formation in this region have shown that the light factor determines oscillations of spring wheat yield up to 8%, thermal – up to 12% and 80% of yield crop oscillations is connected with moisture factor (Lebed, 1991). Under conditions of regional climate change in Kazakhstan, there is the tendency to increase moisture consumption for 1 unit of grain production.

Evapotranspiration is one basic characteristic of a crop water regime, which is exposed to the climate change impact. The evapotranspiration calculations over Northern Kazakhstan for the period 1974–2003 (base period) were executed for possible change assessment of the evapotranspiration of the spring wheat sowing. The Penman-Monteith method, advised by the FAO, was used for this purpose (Crop Evapotranspiration, 1998). According to the FAO, water use values calculated that way in different world regions are comparable enough to determine water use values actually spent by plants. In 2002 the specialists of the RSE "KazNIIEK" calculated ETo and

ETc for some agricultural cultures over Almatinskaya oblast by this method for the period 1997–2001 (The Report of KazNIIMOSK, 2002). The matching of the calculated evapotranspiration values with actual values obtained by the Kazakh Research Water Management Institute in field conditions has shown a 10–15% difference (Orocitel'niye, 1989).

The following equation is the basis of the Penman-Monteith method:

$$ET_0 = \frac{0,408 \times \Delta \times R_n + \gamma \times \dfrac{900}{T + 273} \times U \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0,34U)} \quad (1)$$

where ET_o – evapotranspiration by "standard" sowing (mm/day)
R_n – radiation balance of underlying surface ($MJ/m^2/day$)
T – average day temperature of air (°C)
U – speed wind (m\s)
Es – vapor pressure at maximum saturation (kPa)
Ea – actual vapor pressure (kPa)
γ – psychrometric constant (kPa/°C)
Δ – curve slope of vapor pressure (kPa/°C)

The "standard" sowing ETo is hypothetical crop with altitude 0.12 m, surface resistance 70 s/m and albedo 0.23. It reflects different weather conditions influencing evapotranspiration.

The dynamic analysis of the average annual air temperature in Northern Kazakhstan has shown an increase in the air temperature of 0.2°C and an increase in the warm period duration from 177 days up to 183 days for the period 1974–2003. The resulting ETo values for the warm period have shown changes of 1.3–1.9 times from year to year and good correlation of ETo with spring wheat yield (Appendix, Figure 1). The evapotranspiration by "standard" sowing decreased 6% for this period. The ETo value reduction occurred basically because of a 2–3% increase in relative air humidity and reduction in wind speed. The increase in air humidity is connected to precipitation increases for 1971–2000 in this region

3. The assessment of possible changes in the crop water regime under global warming impact

Climate change scenarios for Northern Kazakhstan based on modern versions model results of the atmosphere and ocean general circulation (CCCTR, CSI2TR, ECH4TR, GISSTR, HAD2TR) were used to calculate possible changes in evapotranspiration from spring wheat sowing in 2010 and 2050. According to the results of this analysis, by 2010 it is expected that evapotranspiration will increase up to 2.6%. It is possible that such a small change is a result of the rough spatial resolution of global climate models, which are inadequate for the description of local climate changes and corresponding agroclimatic values over such a short time span. The calculations to 2050 have shown a more substantial increase – 27.6%. (Appendix, Figure 2). The territorial distribution ETo demonstrates a more considerable increase in northern and northwest regions of Northern Kazakhstan (27–35%) and lesser increases in the west and south (about 21%).

The evapotranspiration from spring wheat sowing ETc were obtained by the formula (2) with use of water consumption seasonal coefficients Ks:

$$ETc = ETo * Ks \tag{2}$$

The coefficients Ks are the result of empirical observations for spring wheat sowing evapotranspiration using a lysimeter. These observations were executed by the Research Water Management Institute of the Agriculture Ministry of the Republic of Kazakhstan.

The calculations have shown (Appendix, Table 1) that, on the average for spring wheat vegetation period from shoots up to wax ripeness, the evapotranspiration intensity by sowing (optimum moisture availability under normal conditions) can be increased by 2050 up to 0.57–0.90 mm/day for southern meteorological stations and about 1.30–1.56 mm/day for northern stations (12–19% and 31–41% accordingly). The maximum changes in evapotranspiration intensity can be observed in the interphase period from the early stage of shooting before blooming (up to 2.28 mm/day) at the modern evapotranspiration intensity during this period about 5–8 mm/day. The evapotranspiration calculations by sowing were realized for three terms of spring wheat sowing, which is the current practice in Northern Kazakhstan.

The research results confirm a possible increase in evapotranspiration by spring wheat sowing in the yield formation period because of air temperature rise.

Thus, the evapotranspiration by crop sowings will increase depending on global warming in Northern Kazakhstan. The increase in evapotranspiration will cause possible aggravation of atmospheric and soil intensity droughts, decrease in spring wheat yield, and reduction of areas suitable for spring wheat cultivation. Therefore, further development of Kazakhstan grain production should be elaborated considering adaptation to possible climate change.

4. Conclusion

1. Grain production dynamics in Northern Kazakhstan have an unstable nature. About the 60–70% of the total production risk in Kazakhstan grain production is connected with weather and climate dynamics.

2. In the arid conditions of Northern Kazakhstan, the major factor limiting crops is moisture. 80% of crop yield oscillations are connected with the moisture factor.
3. Under conditions of global warming in Kazakhstan it is expected that moisture consumption will tend to increase per 1 unit of grain production. The evapotranspiration received ETo data for Northern Kazakhstan have shown that by 2010 evapotranspiration is expected to increase up to 2.6% and by 2050 – 27.6%. For spring wheat vegetation period from shoots up to wax ripeness, the evapotranspiration intensity by sowing can increase by 2050 up to 0.57–0.90 mm/day for southern meteorological stations and about 1.30–1.56 mm/day for northern stations (12–19% and 31–41% accordingly). The maximum changes in evapotranspiration intensity can be observed in the interphase period from early stage of shooting before blooming (up to 2.28 mm/day) at the modern evapotranspiration intensity during this period about 5–8 mm/day.
4. In Northern Kazakhstan major region of spring wheat sowings, possible evapotranspiration increase could lead to an increase in the intensity of soil droughts, which would reduce the areas suitable for spring wheat cultivation and decrease spring wheat yield.

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APPENDIX

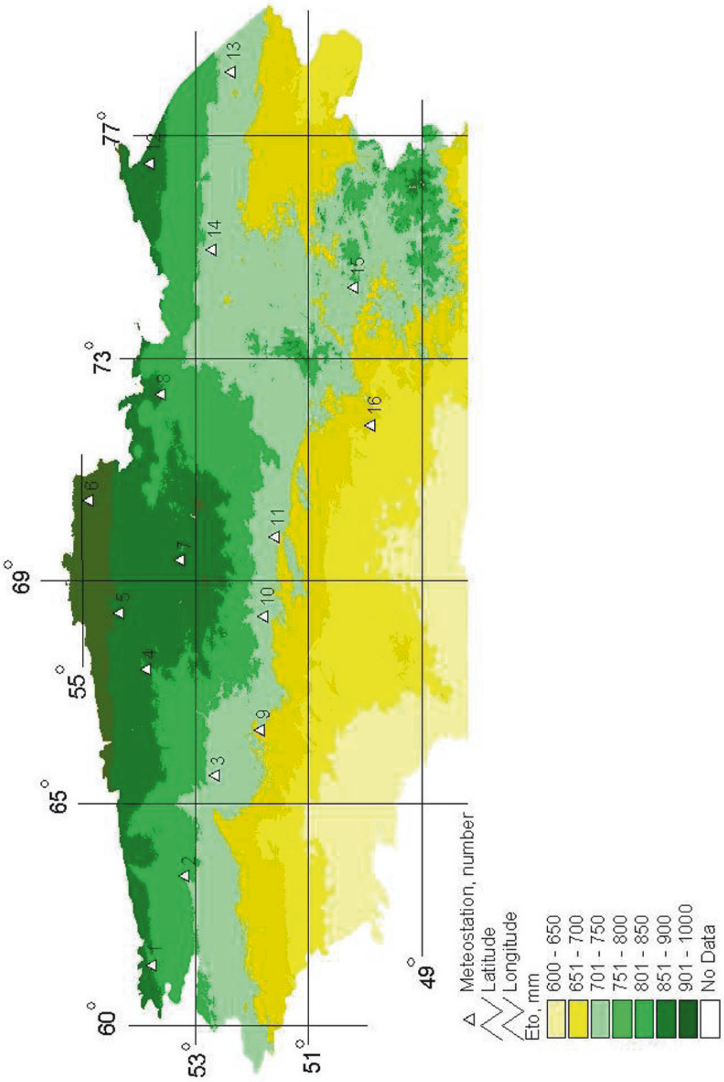

Figure 1. The average evapotranspiration ETo (mm) of the agricultural fields by "standard" sowing for warm period 1974–2003 over Northern Kazakhstan.

Meteostations: 1 – Komsomolets, 2 – Kostanay, 3 – Karasu, 4 – Sergeevka, 5 – Yavlenka, 6 – Bulaevo, 7 – Kokchetav, 8 – Kzyiltu, 9 – Esil, 10 – Atbasar, 11 – Zhaltyir, 12 – Mikhaylovka, 13 – Scherbaktiy, 14 – Kominterovskaya, 15 – Korneevka, 16 – Chkalovo

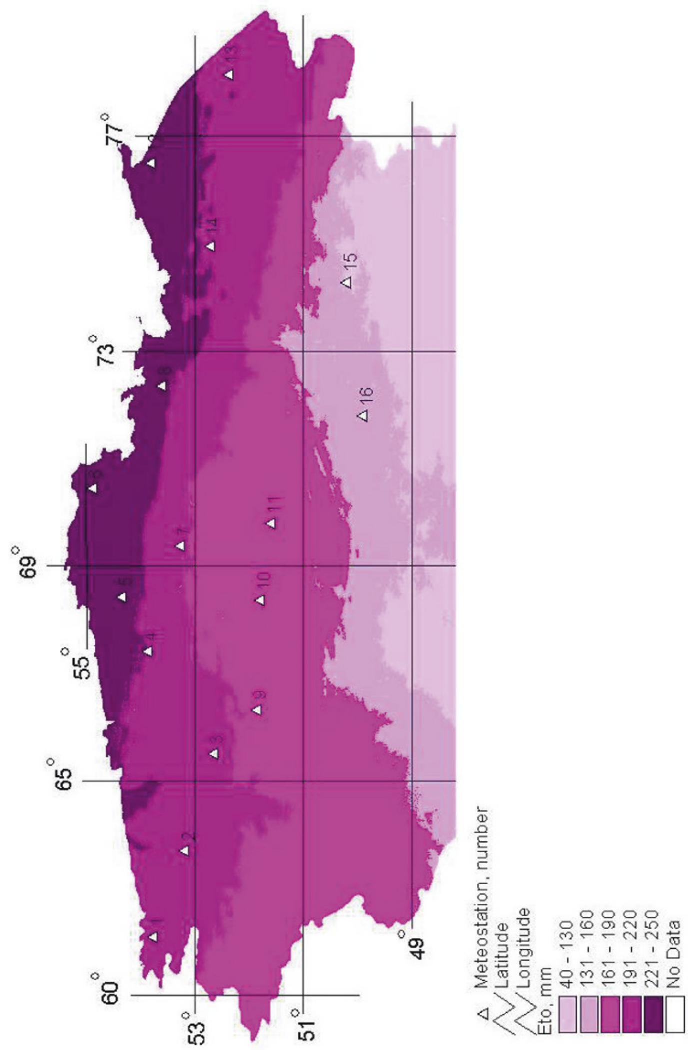

Figure 2. The possible change of the evapotranspiration ΔETo of the agricultural fields by "standard" sowing in Northern Kazakhstan to 2050 year.

Meteostations: 1 – Komsomolets, 2 – Kostanay, 3 – Karasu, 4 – Sergeevka, 5 – Yavlenka, 6 – Bulaevo, 7 – Kokchetav, 8 – Kzyiltu, 9 – Esil, 10 – Atbasar, 11 – Zhaltyir, 12 – Mikhaylovka, 13 – Scherbaktiy, 14 – Kominterovskaya, 15 – Korneevka, 16 – Chkalovo

TABLE 1a. The evapotranspiration intensity in mm/day by spring wheat sown in Northern Kazakhstan and possible change in evapotranspiration to 2050 under climate change influences. Climate models CCCTR, CSI2TR, ECH4TR, GISSTR, HAD2TR (Data were compiled by Lebed and Akhmadiyeva in 2006).

Meteo-station	Latitude	Alt. (m)	Year	Date sown	ET (mm/day)				
					Shoots-tilling	Shooting	Ear formation-blossoming	Milk ripe-wax ripe	Shoots-wax ripe
1	50.22	628	1974–2003	11.05	3.69	6.35	6.33	4.25	4.78
				21.05	3.80	6.27	5.60	3.81	4.73
				31.05	4.00	6.06	6.21	3.63	4.75
			2050	11.05	3.86	6.93	7.44	5.05	5.35
				21.05	4.19	7.06	7.12	4.81	5.48
				31.05	4.42	7.07	6.76	5.09	5.65
2	51.81	302	1974–2003	11.05	4.03	6.53	6.50	4.74	5.09
				21.05	3.93	6.69	6.29	4.49	5.05
				31.05	4.27	6.81	6.47	4.04	5.05
			2050	11.05	4.20	7.50	8.44	6.57	6.37
				21.05	4.76	8.63	8.06	5.21	6.32
				31.05	5.04	7.93	8.14	5.28	6.20
3	52.40	148	1974–2003	11.05	4.07	7.07	7.53	3.50	5.80
				21.05	4.12	6.40	6.10	4.09	4.96
				31.05	4.28	6.47	6.25	4.00	4.95
			2050	11.05	4.54	7.61	8.40	5.72	6.17
				21.05	4.78	8.28	8.27	5.35	6.36
				31.05	5.23	8.23	7.50	4.95	6.24
4	53.78	177	1974–2003	11.05	3.82	6.60	5.55	4.12	4.71
				21.05	3.78	5.69	5.28	3.40	4.34
				31.05	3.88	5.42	5.10	3.18	4.20
			2050	11.05	3.88	7.07	7.00	4.30	5.26
				21.05	4.50	7.28	7.19	4.43	5.57
				31.05	4.82	7.70	6.76	4.73	5.65

Meteostations: 1 – Komeevka; 2 – Atbasar; 3 – Scherbaktyi; 4 – Komsomolets

TABLE 1b. The evapotranspiration intensity percentage by spring wheat sown in Northern Kazakhstan and possible change in evapotranspiration to 2050 under climate change influences. Climate models CCCTR, CSI2TR, ECH4TR, GISSTR, HAD2TR (Data were compiled by Lebed and Akhmadiyeva in 2006).

Meteo-station	Latitude	Alt. (m)	Year	Date sown	ET (%)				
					Shoots-tilling	Shooting	Ear formation-blossoming	Milk ripe-wax ripe	Shoots-wax ripe
1	50.22	628	1974–2003 2050	11.05 21.05 31.05 11.05 21.05 31.05	0.17 (5) 0.39 (10) 0.42 (10)	0.58 (9) 0.79 (13) 1.01 (17)	1.11 (18) 1.52 (27) 0.55 (19)	0.80 (19) 1.00 (26) 1.46 (40)	0.57 (12) 0.75 (16) 0.90 (19)
2	51.81	302	1974–2003 2050	11.05 21.05 31.05 11.05 21.05 31.05	0.17 (4) 0.83 (21) 0.77 (18)	0.97 (15) 1.67 (28) 1.12 (16)	1.94 (30) 1.77 (28) 1.67 (26)	1.83 (39) 0.81 (18) 1.19 (29)	1.28 (25) 1.27 (25) 1.15 (23)
3	52.40	148	1974–2003 2050	11.05 21.05 31.05 11.05 21.05 31.05	0.47 (19) 0.66 (16) 0.95 (22)	0.54 (8) 1.88 (29) 1.76 (27)	0.87 (12) 2.17 (35) 1.25 (20)	2.22 (63) 1.26 (31) 0.95 (21)	0.37 (6) 1.40 (28) 1.29 (26)
4	53.78	177	1974–2003 2050	11.05 21.05 31.05 11.05 21.05 31.05	0.06 (2) 0.72 (19) 0.94 (24)	0.47 (7) 1.59 (28) 2.28 (42)	1.45 (26) 1.91 (36) 1.66 (32)	0.18 (4) 1.03 (30) 1.55 (49)	0.55 (12) 1.23 (28) 1.45 (34)

Meteostations: 1 – Komeevka; 2 – Atbasar; 3 – Scherbaktyi; 4 – Komsomolets

Pasture in Kazakhstan.

ESTIMATING AGRICULTURAL ADAPTATION TO CLIMATE CHANGE THROUGH CLOUD ACTIVATION FOR NORTHERN KAZAKHSTAN

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Abstract. This chapter presents the results of a cloud moisture source analysis employing meteorological radar over northern Kazakhstan and meteorological station data in the radar coverage limit zone.

Keywords: Woolpacks, convectional flows, moisture sources, distance, radar resolution, terms of observation, precipitations, dew-point

1. Introduction

The Republic of Kazakhstan is located in Central Asia between 39°49′ – 55°49′ N. and 46°28′–87°18′ E. in the interior of the Eurasian continent. Kazakhstan is the ninth largest country in the world with a total area of 2,727,300 km^2. The territory of the republic is located in four natural landscape zones: forest-steppe, steppe, semi-desert, and desert. The climate of the country is sharply continental. Most of Kazakhstan's territory is situated in so-called marginal zones, which are very vulnerable to climate change.

A major branch of the agricultural sector is the animal industries. Agriculture and grain manufacturing are concentrated in northern Kazakhstan. The most important agricultural crop is wheat, which is known for its very high quality. The demand for wheat, both at home and at external markets, remains high. Therefore, we have investigated cloud moisture sources during the growing season and addressed the possible impact of additional

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precipitation on agriculture activities in northern Kazakhstan under a changed climate. Results appeared encouraging and could be used in future, more detailed studies as well as for practical action planning.

Since the Republic is predominantly agrarian, the problem of climate change is sharp and actual. According to expert analysis, agrarian countries will be the first to suffer under global climate change impact while industrial countries will experience the least losses (PCC, 2001). For this reason, there are a number of national programs investigating the potential effect of climate change on the Republic.

2. Objectives

Forecasted climate change in northern Kazakhstan is compared to conventional data (IPCC, 2001; Israel, 2003; Meleshko, 2004, etc.). Modern available Global Climate Models can reliably forecast world-wide temperature and precipitation changes decades into the future. However, the model output cannot be applied to regions without downscaling to account for local departures from the estimated temperature and precipitation change offered in climate change scenarios. In addition, in certain regions, temperature and precipitation change may even have a negative trend.

3. Exploration methods

Expected changes in climate in the twenty-first century within northern Kazakhstan are examined using techniques recommended by the Intergovernmental Panel on Climate Change (Nakicenovic et al., 2000), which also established estimates for the Eurasian continent including Russia (Israel, 2003; Meleshko, 2004, etc.). In addition to this data, calculations obtained by other techniques, including data from the region's meteorological stations, are employed to determining whether climate change scenarios can provide useful predictions 10 years into the future. Climate prediction in general can be very challenging because of an inexact understanding of the initial conditions of the ocean-atmosphere-cryosphere-biosphere climate system. Predictability becomes greater for calculations of climate change under the influence of greenhouse gases. (Trenberth et al., 2002, etc.) The continuous accumulation of greenhouse gases contributes to the non-equilibrium conditions of the climate system. Ocean, the most inertial climate system component, reacts to greenhouse gas atmospheric concentration changes very slowly, with a delay of up to 10 years. Modern climate change appears to be the consequence of the accumulation of greenhouse gases during the past few decades. Considering the dynamics of atmospheric greenhouse gases during the past few decades compared to long-term accumulation, a higher degree of predictability in climate change due to the anthropogenic component of approximately 50 years can be expected. Thus, the results of such forecasts deserve high attention to seek out its adaptable mechanisms.

In this case, the choice of atmospheric general circulation models was not a difficult one. Within the framework of participation in international projects, models containing two scenarios of emissions A1 (9 scenarios) are used and B2 (14 scenarios) (IPCC, 2001, etc.) despite the existence of more than 20 applicable models. Scenario B2 is taken as the base.

Climate change is examined in relation to the base climatic period of 1981–2000. By the middle of the twenty-first century, the winter air temperature above northern Kazakhstan should rise by 3°C and by the end of the century the increase in temperature should be between 4.0°C and 4.5°C. In the middle of the twenty-first century the summer air temperature will rise approximately 2°C and by the end of the century, there should be a 4°C increase. The seasonal transitions throughout the year remain within the limit of a confidence interval. By the middle of the twenty-first century, the annual temperature rise in the region will reach 2.5–3.0°C which will increase to 4.0°C by the end of the century.

There will also be an increase in precipitation. By the middle of the twenty-first century, winter precipitation should increase by 7–9% and by the end of the century there should be a 10–12% increase. The increase in summer precipitation will probably range from 5% in the middle of the century to less than 3–5% at its end.

As the temperature rises, precipitation evaporation from land surface likewise increases. In turn, the active layer moisture content of the soil is reduced. Moisture content reduction can be expressed through the formula:

$$MC = P - E$$

Where MC is moisture content, P is precipitation, and E is evaporation. Analysis of average precipitation from 1981–2000 suggests that the moisture content will be reduced by 8% by the middle of the century and 5% by the end of the century. During the century, the precipitation cycle will continue as before (Drozdov, 1971; Chichasov, 1991). The typical cycle for northern Kazakhstan lasts for approximately 15–18 years (Drozdov, 1971). Observations up through 2006 suggest that the cycle is now on its ascending branch. In general, the cyclic fluctuation affects precipitation by approximately 10%. Different cycles, however, will vary.

Cyclic fluctuations are the consequence of natural changes in the climate system and therefore cannot be predicted. These fluctuations are imposed on an anthropogenic trend of precipitation with similar magnitude. Fluctuations on the descending part of the cycle can reduce the quantity of precipitation by 10% or more.

Departures from the normal precipitation cycle can still take place. A decrease in the amount of annual precipitation is two times more probable than an increase. Thus, precipitation fluctuation in the long-term can vary from the norm up to 15–50% in a scenario of steady temperature growth and reduced soil moisture content. This effect underlines the necessity of adaptable regional downscaling methods, not only for addressing anthropogenic climate change, but also because of natural variations in dryness and variable annual precipitation totals.

To address an increased precipitation scenario, the adaptable downscaling method we shall consider employs initially cloudy synoptic weather conditions. The average annual precipitation in an agricultural region is approximately 370–250 mm. The precipitation maximum of 45–70 mm occurs in June and during the growing season, i.e. from May until September, 65–75% of the average annual precipitation falls (Government of Kazakhstan, 1990). Thus, despite the small volume of annual precipitation in northern Kazakhstan, precipitation is distributed advantageously for agriculture.

Analysis of the annual precipitation distribution suggests that precipitation during the warm season would have the most impact on the growing season. It is known that convective clouds supply most of the precipitation in the summer season. For northern Kazakhstan, up to 25% of growing season precipitation comes from stratiform clouds, which occur with or slightly after the end of convective rainfall.

While we acknowledge the impact of stratiform clouds on seasonal precipitation totals, the object of this study is to assess precipitation of convection origin (cumulonimbus and similar clouds associated with convection). We have studied long-term synoptic weather and thermodynamic conditions of precipitation initiation. We note that thunderstorms and rainfall in the region develop under more rigid conditions than, for example, above the European part of Russia (Rukovodstvo, 1985). Thus, convection in the region can develop when dew point depressions at levels of 850, 700 and 500 hPa are greater than 25°C. For the European part of Russia such conditions are considered impossible (Rukovodstvo, 1985, etc.). In this case, a lack of moisture is compensated by higher convective instability of the first kind, due to higher surface temperatures and an adiabatic lapse rate in the bottom layer of an atmosphere. A number of other factors influence the formation of convective clouds, showers, and thunderstorms in this region.

However, the most important aspect of this problem is to define the moisture content in the clouds. Moisture content and the active influences on convective clouds in the region were studied over a period of 60 years. (Gemgoltz, 1973). An instrumented aircraft which only flies in good weather and during daylight hours was used to explore these processes. Thus, estimates of convective cloud moisture content were not possible.

Research was later halted due to insufficient funding. The data received at that time about convective clouds expanded understanding of physical parameters and the moisture content of clouds in the region.

Radar-derived moisture contents in Kostanai, Pavlodar and Astana were collected every 3 hours. Meteorological radars have two modes of supervision: short range and long range reflectivities. Short range reflectivites generate data in four quadrants within a 40 km radius. Thus, practically all clouds are captured, generating information about their top and bottom borders, and their horizontal size in a vertical section at three levels. Long-range reflectivities scan a 300 km radius on a yielding 30 × 30 km square data area. However, the probability of cloud detection is gradually reduced at radii greater than 150–200 km, requiring special processing methods to produce comparable results (Cherednichenko, 2000). We employed this method to generate cloud fraction and convective cloud frequency maps for different months, over the territory covered by the radar.

This area was selected for observations with short-range reflectivity. We also determined convective cloud frequency, their characteristics for each quadrant and then as a whole in short-range reflectivity detections.

As a result of a 3-year investigation for each month of the growing season and the basic characteristics of cloud cover, situations in which conditions that favor convective activity were established. The clouds which had sufficient moisture content were not included in the calculations. Kostanay was used as an example. Thus, it is considered that short-range reflectivity is accessible in relation to moisture content and its affect on convective clouds (Prikhot'ko, 1968), allowing precipitation to increase 20–22%.

The forecast of moisture content in long-range reflectivity is more complex since the influence of orography does not allow short range reflectivity data to be applied to all of the territory covered by radar.

Therefore, it is extremely important to establish a degree of concurrence or a degree of affinity between estimates of the phenomena according to meteorological stations and meteorological radar, as well as observations in short-range and long-range reflectivity. Only in cases of sufficient affinity will the joint analysis of the data be possible.

The four meteorological stations (MS) of Kostanai, Mikhailovka, Rudny, and Tobol were selected, located 40, 50 and 100 km from Kostanai respectively. Regular precipitation observations from MS data and radar-tracking reflectivity at levels II and III were collected in April, July and October. The results of the synchronous observations have been presented in dependence graphs of precipitation quantity from the size of radar-tracking reflectivity for every MS. Radar-tracking reflectivity was first undertaken at level III (an isotherm – 22°C) but was reduced to a level II (the zero isotherm) when level III produced no data. This approach is standard in radar meteorology. Figure 1 shows the dependence between precipitation quantity in the MS data and radar-tracking reflectivity in the data for the above listed stations. Concerning dependencies at Kostanai, relationships between radar-tracking reflectivity and the quantity of precipitation are parabolic for all seasons: the left-most parabola for April and the right-most for October. Hence, at the same value of radar-tracking reflectivity, April exhibits minimum precipitation while the maximum occurs in October. In July the range of reflectivity change reaches its maximum positive value and October's values are at a minimum, extending further into the negative than in other seasons. The range of reflectivity change corresponds to the overcast conditions, observable in each season. A curve in the zero and negative reflectivity magnitudes indicates a high occurrence of simultaneous stratiform and convective clouds.

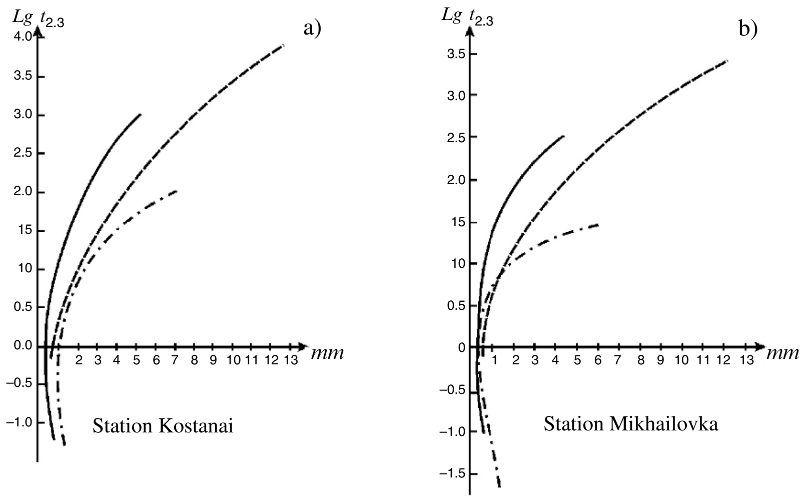

Figure 1. The dependence of precipitation quantity (mm) from reflectivity (Lg).

Similar dependencies are observed for Mikhailovka, Rudny and Tobol (not represented in the Figure). However, fewer precipitation categories can be detected with greater distance from the radar. This is caused by the weakening of the active cloud to radar signal (Rukovodstvo, 1985, etc.). The value of this weakening is an important characteristic which should be used to analyze the clouds, precipitation and thunderstorms in the zone of radar coverage.

Table 1 depicts the comparison of data from meteorological stations with radar data. The reliability of MS data is assumed to be 100%. From this data it can be seen that in Kostanai the radar detects 96% of convective clouds, 90% of heavy rainfall and 97% of thunderstorms. As the distance increases, the dependence between MS and radar data decreases and in Tobol detects an acceptable 80% of all events.

TABLE 1. Comparison of data from meteorological stations and radar.

Station	Distance to station (km)	Radar data (%)		
		Precipitation	Hail	Storm
Kostanai	0	96	90	97
Mikhailovka	40	88	83	89
Rudny	50	86	81	84
Tobol	100	80	72	79

Table 2 represents the same phenomena, but with the assumption that the radar data are 100% reliable. The data for the Kostanai MS confirm only 82% of convective cloud cases and 50% for thunderstorms cases. As distance increases, the concurrence of radar and MS data grows, achieving 90% for the Tobol MS located 100 km from the radar source.

TABLE 2. Comparison of radar and meteorological station data.

Station	Distance up to station (km)	Radar data (%)		
		Precipitation	Hail	Storm
Kostanai	0	82	88	80
Mikhailovka	40	86	90	84
Rudny	50	87	90	86
Tobol	100	93	95	89

The radar not only resolves the phenomenon, but also the boundary conditions; for example, the radar detects a thunderstorm as well as the accompanying cloud type while the observing MS marks only the phenomena, such as a thunderstorm, a shower and so forth. For aircraft, both the boundary conditions and the phenomena are important. Therefore, the radar detects more of the phenomena, particularly with short-range reflectivity. With distance observations, however, radar is less reliable. With a radius up to 180 km radar measurements should be accurate. However, radar should not be relied upon in isolation.

4. Conclusion

After analyzing the data from both meteorological station observations and from radar with short-range reflectivity, it appears that the radar data captures spatial variability of convective cloud frequency, and with distance correction it is possible to account for the variability of moisture content calculated short-range reflectivities. In this case, radar data within 200 km can account for 16–28% of normal precipitation.

While these results are preliminary, it seems apparent that the potential of active influences as the adaptation mechanism of climate change can yield positive results. Furthermore, active influences can compensate for conditions of climate change in regions with precipitation shortfalls due to casual fluctuations of the climate system during some years.

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DYNAMICS AND STRUCTURE OF TOTAL OZONE CONTENT OVER THE REPUBLIC OF KAZAKHSTAN IN CONDITIONS OF GLOBAL WARMING

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Abstract. This chapter describes both the total ozone content (TOC) field types over the Republic of Kazakhstan and the weather situations that cause extreme TOC concentrations, amid wider trends of global warming.

Keywords: Total ozone content (TOC), circulation, invasion, jet flows, warmth crest, cyclone, anticyclone

1. Introduction

Global warming is an effect recognized by most climate specialists of the world. Reasons for climate change are predictors for future possible changes and are the object of study for many meteorologists. One popular focus of research is atmospheric ozone variability that has a range of peculiarities that were not apparent before the onset of global warming.

Atmospheric ozone variability above the Republic of Kazakhstan after the 1950s had not been investigated. However, the increased attention to this problem by the world community and the range of international conventions that have been sponsored by the Republic of Kazakhstan made these investigations inevitable. In this study, we explore total ozone content (TOC) variability over Kazakhstan for the period between 1998 and 2006 using TOC data (over the Atlantic and Pacific oceans) implementation.

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1.1. TOC DISTRIBUTION OVER THE TERRITORY OF THE REPUBLIC OF KAZAKHSTAN

TOC distribution over the territory of Kazakhstan is sensitive to large-scale atmospheric circulations that span above a considerable portion of the Northern hemisphere. The spatial size of the area under consideration dictates that we choose this approach. There are four stations measuring TOC within Kazakhstan, but the quality of the data is often poor. The availability of TOC data from adjoining territories allows us to maintain spatial control.

All the TOC average monthly data have been applied to Kazakhstan at its relative central point. In the table below, for example, are listed average

TABLE 1. Fields forms, average and experimental TOC values over Kazakhstan.

	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
2004												
Field form	С	С	С	$Л_{Ю}$	$Н_{ЮС}$	$Н_{В}$	$Г_{Ю}$	$Г_{Ю}$	$_{Раз}Г$	$Г_{Ю}$	$Г_{Ю}$	$Г_{Ю}$
Average	2	3	-2	3	-3	0	2	3	1	1	2	3
Extreme values	1/-2	3/-2	2/-5	9/-5	-3/2	-5/2	9/-4	8/-2	4/-3	8/-2	7/-2	5/0
2005												
Field form	$Г_{Ю}$	$Г_{Ю}$, $В_{В}$, $Н_{ЗС}$	$В_{В}$, $Н_{З}$	$Н_{ЮЗС}$ на $Г_{Ю}$	$Н_{ЗС}$	$Н_{В}$	$_{Раз}С$	$Г_{Ю}$	$Г_{Ю}$	$Л_{СЗ}$	$Л_{С}$	С
Average	2	2	0	0	0	-2	1	3	2	-4	-4	-2
Extreme values	4/-2	5/-5	2/-2	-5/1	-5/1	-10/1	2/-1	5/-2	3/-2	-5/1	-7/1	-2/2
2006												
Field form	$В_{В}$	$Л_{Ю}$	$Л_{Ю(н)}$	$_{Раз}Н$	$Н_{Ю}$	С	$Н_{В}$	$В_{СС}$	$_{Разм}$	С	С	$Н_{к}$
average	3	-2	-2	-2	-3	-2	3	3	2	2	1	-3
Extreme values	-6/2	-8/2	8/2	-6/-1	-9/0	3/-5	-6/-2	10/0	9/2	2/-2	6/-2	7/-6

Map symbols:			
С	– saddle	$Н_{З}$	– low, western
$Л_{Ю}$	– southern hollow	$В_{В}$	– high, to the East from Kazakhstan
$Н_{Ю}$	– low, South Siberia	$Н_{ЗС}$	– low, western Siberia
$Н_{В}$	– low, to the East from Kazakhstan	$Н_{В}$	– low, eastern
$Г_{Ю}$	– southern crest	$Н_{к}$	– low over the Kazakhstan
$_{Раз}Г$	– diffused crest	$В_{СС}$	– high, northern Siberia
$_{Раз}Н$	– diffused low	$Л_{СЗ}$	– hollow on the North-West
$Н_{ЮЗС}$	– low, southwestern Siberia	$Л_{С}$	– hollow on/to the North

and extreme TOC data over Kazakhstan and its adjoining territories. These data have been derived by the means of classifying monthly average TOC fields for the period from 2004–2006. The field forms are too detailed at present, since they currently have an undefined value. There are only 5–6 form varieties.

As can be seen from the table, the TOC deviation value defined for the center of Kazakhstan changes slightly, by 2–3%, or rarely by 4%, over the norm. These values appeared atypical for this large area, which would be expected to follow the mean more closely. To account for this, monthly deviation extreme values were also determined for the Kazakhstan area.

The range of such deviations was rarely lower than 5% and often exceeded 10%, the values averaging 6–7%. In the future, the forecast of Kazakhstan TOC values shall be very complicated due to the wide range of spatial deviations.

To address this issue, we have developed and proposed a TOC field classification over the Kazakhstan territory which may further be implemented in a TOC forecast.

2. Abnormity occurrence

TOC values may shift slowly from minimum to maximum, occurring over a monthly period, or they may shift dramatically, affecting an average monthly TOC value.

It can also happen that the norm deviation retains the same sign (+/-) during one or more seasons. Occasionally, huge and significant anomalies observed in some regions overcome TOC anomalies with opposite sign during the monthly period (Bekoryukov et al., 1990; Kadygrova et al., 1990).

TOC anomaly sustainability could significantly simplify its forecast (for instance, by means of an elementary temporary correlation). For now, its variability is difficult to forecast.

Data from the Kazakhstan stations are not sufficient to formulate a solution to the problem. In addition the quality of their data is not comparable to that of international stations. We have applied for data from adjoining territories. To enhance our data we synthesized all the information that could be acquired on TOC monthly value variability. The results are found in Table 2.

As can be seen in the above Table TOC daily values were above the norm during several months in Charjou. At the same time, a high deficit of TOC over Siberia and Kazakhstan occurred in May 2006 for 6 days. This short period was enough to lower the TOC average value below the norm.

Both cases occur quite often, as can be seen in Table 2. In (Kadygrova et al., 1990) one can see that in subtropical latitudes temporary TOC change is lower than in temperate zones. This can be seen in Table 2. Thus, it is quite possible that TOC monthly average anomaly forecasting would be more successful in the Southern part of Kazakhstan than on the Northern part of territory, should such a need arise.

TABLE 2. Ozone extreme values over the territory of Kazakhstan.

Region	Month	Год	Deviation type	Character
Yekaterinburg	April	2004	Above the norm	Extremely high data
Petropavlovsk-Kamchyatsky	May	2004	Deficit lower the abnormity level	Extremely low TOC on the 3 days period duration
Ciberia and Kazakhstan	May	2004	Lower the norm	Ozone abnormity observed during 6 days period
ETP	Decmber	2003	Lover the norm	Regular values during the month on the abnormally high background temperature values
Charjou	Third quarter	2004	Above the norm	Daily high TOC values
Hunty-Mansuiysk	April	1999	Above the norm	Regular values on the month period duration
Central Asia and Kazakhstan	April	1999	Abnormally high	On the third and second decades
Ciberia	May	1999	Abnormally low	Second half of May
ETP	May	1999	Above the norm	Daily high values
Krasnoyarsk	June	1999	Deficit	During the month (four times were obtained as values of positive deviations)
Karaganda	October	1999	Maximum deficit	Long periods of TOC positive deviations
Ashabat	December	1999	Maximum deficit	Long periods of TOC negative deviations

Results of TOC investigations into the spatial distribution of monthly, seasonal and annual TOC values over the eastern part of the Northern Hemisphere and Kazakhstan reveal:

- The variability of TOC values over Kazakhstan was divided into a few classifications with rather frequent appearance.
- Considering that each particular type is formed due to specific circulation conditions, it is vital to study those conditions. Being aware of monthly, seasonal, or annual forecasting makes it possible to develop reliable forecasting methods of TOC norm deviations.

TOC monthly value structures are rather complicated. They can be smoothly increasing (decreasing) in relation to the normal value of the total ozone content change process, making the corresponding month atypical. These anomalous results may also derive from short time (2–3 days, 35–40%) dramatic deviations, which later appear in the TOC monthly average calculations. The complicated nature of forecasting derives from varying situations such as these.

We examined a selection of extreme TOC cases over Kazakhstan, focusing on periods when the TOC value varies by 2.5 or more of the quadratic average in Kazakhstan. After examining weather conditions as they appear in cases with extreme TOC values, one particular extreme case was taken as an example.

2.1. SEPTEMBER 20, 2006 IN SEMIPALATINSK

According to the surface analysis, there were two cold atmospheric fronts moving through Semipalatinsk, coming from the northwest. Behind the cold front, an anticyclone moved in with its center located northwest of Semipalatinsk. The presence of the anticyclone indicates the intensity of the front, confirmed by a 17°C temperature difference along the front. It is also known that surface temperature variations could be disguised by clouds and landscapes.

Nevertheless, map analysis reveals a 15–16°C difference in average temperatures in the lower troposphere after the passing of the cold front. This indicates a strong Northern invasion.

A cold trough at the level of 500 hPa moved from the southwest away from the cyclone that centered northwest of Novaya Zemlya and then along the 70° of eastern longitude to the southwest. Cold air in this trough system had penetrated to the Southern borders of Kazakhstan and into the Central Asia.

According to the surface map, a cold Arctic air mass penetrated to the level of the latitude of Almaty to the West from Semipalatinsk, carrying atmosphere ozone.

At AT-300 the trough is observed very well. At the periphery of the trough was a jet flow, which is especially strong on the southeastern part of the trough, near the fronts. At 300 hPa, wind speed in the jet flow axis is approximately 45–60 m s^{-1}. Semipalatinsk was in this zone.

Extreme ozone concentrations occurred in the deep trough system southwest of its periphery with the influx of the cold arctic air.

2.2. ABNORMALLY LOW TOC IN MAY OF 2004

A case of abnormally low ozone content was observed over the cities of Karaganda and Semipapolatinsk for short time periods on several days. Significant duration weather data over 2 days is studied.

On May 15, a huge cyclone was situated over northeastern Kazakhstan, South of Central Siberia and the Mongolian Republic. Karaganda was under the western periphery of the flow while Semipalatinsk was closer to its center. Two warm fronts were on the far edge of the anticyclone, moving from North of Caspian Sea to the north-northwest, taking a latitude course only over western Siberia.

At OT 500/1000, central regions of Kazakhstan, South of Ural, southwestern Siberia and central regions, were under a large warm ridge, with its axis located to the west of Almaty (Figure 1). The axis situated close to the hypsometric curve was 579–580 decameters, indicating a warm air mass.

At 500 hPa over Northern Kazakhstan, there was an independent high pressure field which also encircled Almaty. The Karaganda and Semipalatinsk meteorological stations were close to the center of the anticyclone (Figure 2).

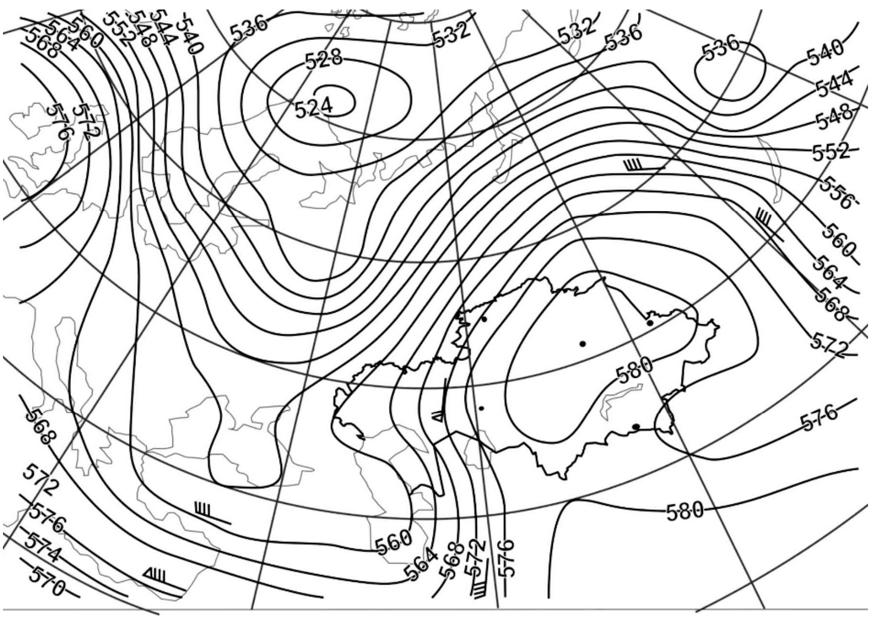

Figure 1. Weather map. Absolute topography (AT), 500 hPa surface, 15.05.04.

At 300 hPa (Figure 2) the air mass between the Aral Sea and Almaty entered as a high pressure ridge and then significantly expanded. The ridge axis and jet flows were far to the northwest of Kazakhstan (Figure 1).

Hypsometric curves at 500 hPa (they concentrated over western Kazakhstan and parallel to the longitudes) indicate that at the closest period of the warmth invasion over the Kazakhstan, there was warmth crest expansion at OT 500/1000 and the system slowly shifted to the East.

On May 16, surface air near the anticyclone had divided into two independent areas of high pressure. In addition, the system had moved to the East.

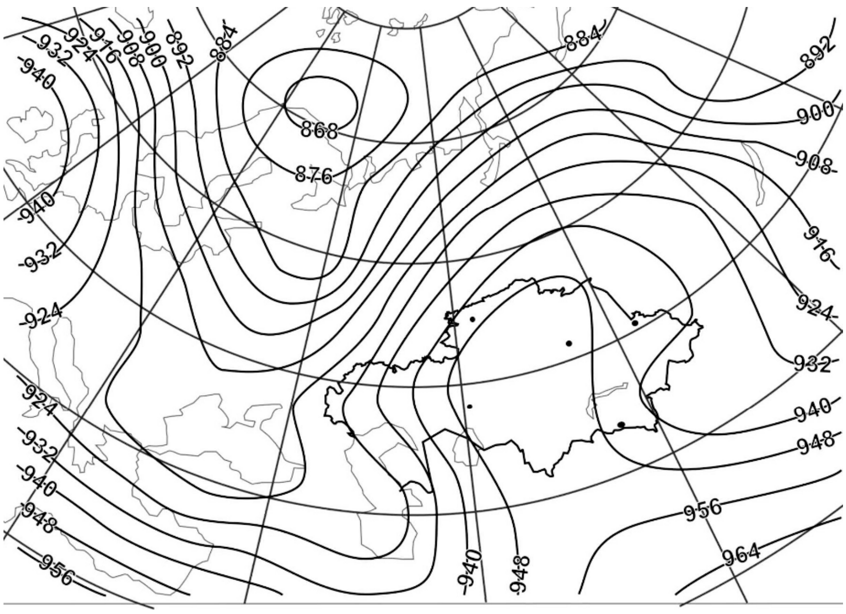

Figure 2. Weather map. Absolute topography (AT), 300 hPa surface, 15.05.04.

At OT 500/1000 the axis of the warm air mass was situated along the longitude between the Aral Sea and Almaty. The temperature of the lower troposphere had increased. While the hypsometric curve value was 560 decameters on May 15, 1 day later it registered at 569 dm, indicating that lower troposphere temperature growth appeared in the central and eastern regions of Kazakhstan (Figure 3).

At 500 hPa over the central and eastern regions of Kazakhstan, there is an independent high pressure field that is encircled in an hypsometric curve of 548 decameters. On May 15, it was 580 decameters, indicating an increase in pressure. However, in southern Kazakhstan there was a small pressure decrease, possibly due to orography. Hypsometric curves above western Kazakhstan are very concentrated and orient longitudinally, leading to warm advection from the South (Figure 4).

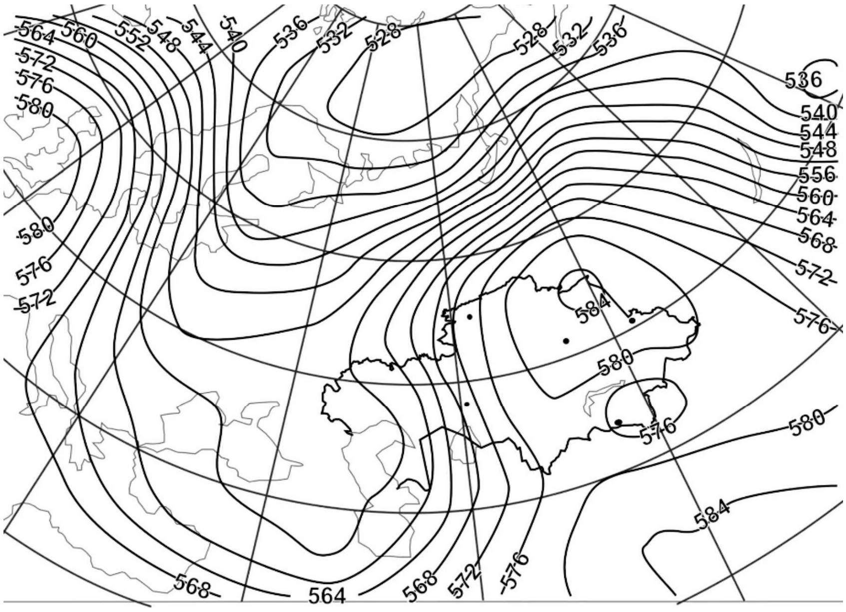

Figure 3. Weather map. Absolute topography (AT), 500 hPa surface, 16.05.04.

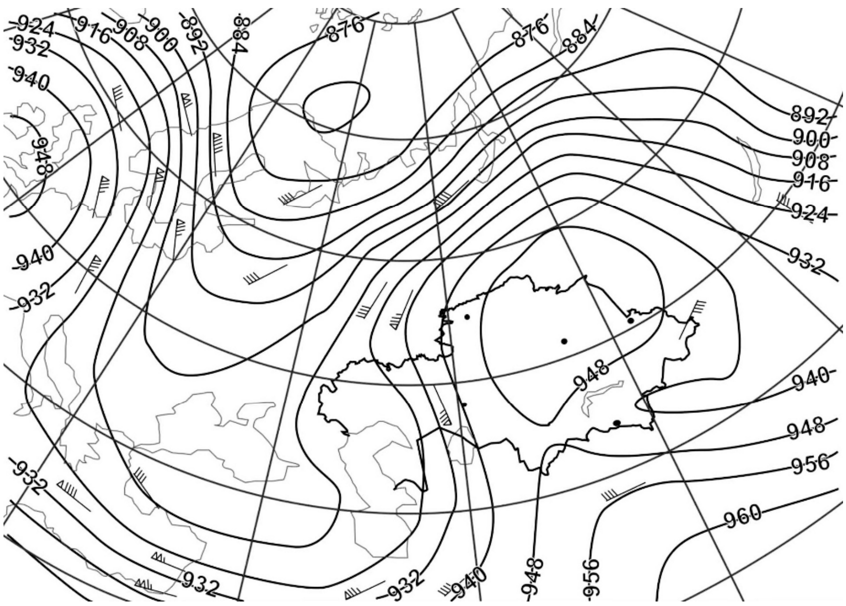

Figure 4. Weather map. Absolute topography (AT), 300 hPa surface, 16.05.04.

An independent area of high pressure encircled in the 948 dm hypsometric curve formed at 300 hPa above northern Kazakhstan and the southern part of western Siberia. Winds above this region are not strong and only in the northwest of the Central Ural were there jet flows (as on the previous day), which head to the northeast. Speed on the axis is approximately 30–40 m s^{-1}, with the hypsometric curves moderately concentrated.

Thus, the TOC deficit is about 2.6–2.7 the quadratic average deviation, and on the next day peaked as an intense tropical air mass shifted longitudinally through the western areas of Kazakhstan. In the upper troposphere (300 hPa), an independent area of high pressure formed revealing the intensity of warm air flow and the speed of shifting system.

As it happened, the TOC deficit above Karaganda and Semipalatinsk remained for several days. But due to shifting weather conditions associated with cold advection over the Almaty, the deficit was not noticed.

3. Conclusion

Deep analysis of all atypical TOC cases allow us to determine quantitative characteristics between TOC over Kazakhstan and circulation parameters that can become a basis for developing forecast recommendations for extreme TOC.

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Steppe landscape in Kazakhstan.

THE CHALLENGE OF WATER PROVISION FOR PASTURE LANDS: A RESTRICTIVE FACTOR FOR LIVESTOCK BREEDING DEVELOPMENT IN KAZAKHSTAN

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Abstract. This study reports on the water supply problem for pasture lands in the Republic of Kazakhstan. It uses data from experiment sites in the watering places of the Bozoy pastures in Kazakhstan's Balkhash region, and it includes an evaluation of mineshaft and tube wells – potential watering points in the pastures of the Balkhash region in the event it is possible to rehabilitate them.

Keywords: Pastures, tube wells, mineshaft wells, watering place, pump, pasture degradation

1. Introduction

In 1980 the area in Kazakhstan comprised of pastures and grasslands was about 186 million hectares, accounting for approximately 70% of all country land sources. Approximately 95 million hectares contained a water provision infrastructure (Kareshev et al., 1983) While the republic was predominantly agrarian, free range cattle breeding development in Kazakhstan was the easiest method of meat and milk production with a prime cost that was several times lower than barn cattle breeding on farms. With free range cattle breeding, all the livestock remains on natural pastures. However, in this situation, the pastures must be supplied with water for the livestock. For

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this purpose, a water supply infrastructure was constructed on the pastures of Kazakhstan with cattle watering points, mineshaft and tube wells, and pasture water pipelines.

2. Pasture water supply prior to 1991

The task of supplying pastures with water anticipates implementing a complex of hydro-technical and soil-conservation measures towards providing livestock with water, raising the productivity of pasture lands and making reserve stocks of forage for livestock.

According to the 1983 KazSSR Gosagroprom data on pasture lands, the following watering sources were constructed on the basis of mineshafts:

- Mineshafts – 37,023
- Water reservoirs – 28,890
- Watering troughs – 31,679
- Enclosed structures – 908

The following watering point sources are based on tube wells:

- Tube wells – 27,353
- Water reservoirs – 25,576
- Watering troughs – 26,987
- Enclosed structures – 17,376

Over 300 artesian wells with a flow rate from 1–20 L/s, sometimes 1–50 L/s, were drilled on the pasture lands of the republic. For oasis irrigation, water from flowing wells was used and small irrigated ploughed areas of 500 ha were established around these wells. Special water supply systems for pastures were constructed for the irrigation of large pasture massifs. Specific attention in their design was paid to the selection of rational routes and of pipe material, the optimal location of watering points, and the structure and parameters of constructions for every watering point.

In the southern Balkhash area (western and south-western districts of Almatinskaya oblast), in the Zhety-Zhal tract, gravity conduits were constructed, including Chengeldinskiy (80 km), Kokpetinskiy (60 km) Sarybukak-Churskiy (47 km). The water supply network was composed of asbestos-cement pipes. Watering points with reinforced concrete storage tanks for 8–15 m^3 of water and 40-m long reinforced concrete toughs were constructed at every 5 km of the water supply system. At each point as many as 800 sheep could be watered. In addition, water supply systems for pastures were put into operation (Terektinskiy, 32 km long; Jamanbalasaiskiy, 35 km long; Koskudukskiy, 25 km long; Samenskiy, 12 km long, and Toguzkudukskiy, 20 km long). These systems anticipated draw-off from capping chambers, open streams and wells. Water flow ranged from 1–20 L/s and the water pressure was within 5–20 m. Watering points were located every 5 km of the water troughs (Figure 1).

On pastures in the eastern and southeastern districts of the Almatinskaya oblast (former Taldykorganskaya oblast), 1785 mineshafts and 248 tube wells were used, as well as 268 km of water supply systems for pastures.

Figure 1. Bozoy pasture cattle watering place.

On pastures in the eastern and southeastern districts of the Almatinskaya oblast (former Taldykorganskaya oblast), 1785 mineshafts and 248 tube wells were used, as well as 268 km of water supply systems for pastures.

The depth of the mineshafts was 10–30 m; the filling depth was 5–15 m. The water was lifted with the help of BLM-100 band units with ZID-4.5 drives. A watering point for a 4–10 m^3 water reservoir contained a reinforced concrete trough 10–25 m long and a watering site 5–10 m wide and 10–30 m long near the well. Capital expenditures for supplying water from mineshafts for 1 ha of pasture in the USSR were 3.2–3.7 rubles and the cost price of 1 m^3 of water was 0.30–0.37 rubles. The depth of the tube wells was 50–100 m. Water was lifted with the help of ETsV type pumps (Figure 2).

Figure 2. Bozoy pasture mineshaft and tube wells.

3. Modern conditions of the pasture water supply

At present the irrigation constructions are unmanaged; the organizations that once used and maintained them have now been liquidated. As a result, power supply systems and pump stations at intake wells and watering points on the pastures were destroyed. Since newly formed farms currently have no rights for the pasture lands, the problem of supplying pastures with water remains. In the Balkhash area, none of water supply systems function at this time and pump stations and power transmission lines have been destroyed (Figure 3).

Figure 3. Derelict pipe station and watering place.

During the first year of the ISTC project K-1396p, active wells of the Sarytau-Kumy pasture massif within the “Southern” research polygon (northwestern part of Almatinskaya oblast) were examined in detail. This pasture massif includes the Karaoy, Bozoy and Anarkhay tracts with an acreage of 740,000 ha, with 518,320 ha having been previously irrigated. Here there were mineshafts and tube wells with good fresh water with a flow rate of 0.1–0.3 L/s. Pastures with an acreage of 34,500 ha were extra-irrigated with water from the Ilye, Kurty and Aksenger rivers. According to the results of pasture surveys in the Bozoy tract and along the Kurty River, currently only one tube well on pastures belonging to farmer Serik Tashibay (N 44°14' 690; E 76° 04' 294) can be used. The other wells in the tract are not used because of the absence of a power supply system and water lifting mechanisms, and because of destroyed watering points and constructions. This circumstance markedly limits the possibility of pasture usage. Due to this lack of water for livestock, pasture lands in the sand desert are restrictively used only in winter and early spring when the thawing snow can provide water.

The most dramatic pasture degradation situation occurs around villages. As it is often difficult to drive the cattle to the remote pastures, the pastures within a 10–15 km radius of villages are highly degraded. In some places there are bald spots (or “*takyrs*”) covered with vegetation unsuitable for livestock.

4. Perspectives on pasture water supply

It should be noted that all watering constructions on the pasture lands of Kazakhstan are currently in the same critical condition. This is why a survey and inventory of all irrigation constructions on pastures of the Southern Balkhash area, as well as on the entire territory of pastures in the republic, is very urgent. It is likewise necessary to develop measures that can be taken towards the reconstruction of the mineshafts and completion of the water-lifting mechanisms for mineshafts and tube wells. Reconstruction of the mineshafts would not be very difficult. Renewal of the tube wells is more laborious because most of the wells were not closed (conserved) and they currently appear to be full of stones and the remains of metal structures.

Data is also available for mineshaft and tube well conditions on the Taukum pastures, as well as an evaluation of the possible rehabilitation of mineshaft, tube well, and cattle watering places and constructions.

At the same time, highly degraded pastures situated near villages and pastures in arid zones are not in use during the summer time because of the lack of watering places for cattle. Most watering place constructions are in an unfit condition without a power supply, mineshaft wells are under-salinized, and pipe stations and watering places have been destroyed.

While Kazakhstan is an agrarian country, where pasturable cattle breeding generally occurs in the cattle breeding sector, all these conditions restrict pasturable stock-breeding development, which in turn hinders the country's economy.

Considering the fact that Kazakhstan's economy is driven by cattle production and its land dominated by pastures, we propose that the government find ways of rehabilitating its pasture lands' water infrastructure in order to facilitate cattle breeding efforts in Kazakhstan's agrarian sector.

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Derelict water well on pastureland in Kazakhstan.

ECOLOGY AND MODERN SOCIO-ECONOMIC CONDITIONS IN KAZAKHSTAN

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Abstract. This study surveys environmental conditions in the Republic of Kazakhstan in terms of: atmospheric pollution, degradation of agricultural lands, production and consumption of waste, water loss and sewage, conditions of irrigated lands, and socio-economic indicators for the Republic of Kazakhstan in 2006.

Keywords: Employment, yield GDP, atmospheric pollution, hydrocarbons, point sources, oil mining, salinization, pastures, waste, sewage

1. Introduction

Environmental conditions in the Republic of Kazakhstan are rather complicated, in spite of the country's huge territory and low population density. According to National Statistics Agency data (2005) on 2006, population density in Kazakhstan was not higher than 2.2 persons per 1 km^2 (Mangystau region). The highest density was observed in South Kazakhstan oblast, up to 18.8 persons per km^2.

The standard of living in the republic is determined by implications of social and economic changes in Kazakhstan. The population of the Republic of Kazakhstan on January 1, 2007 was 15.3946 million. Of those, 7.4 million have borrowed money and the employment level is at 92.2%. Monthly average nominal wages in 2006 has made 40,775 Kazakhstan

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Tenge (KZT) or US$334. The salaries of workers in rural, wood and fishing industries in 2006 increased by 25.6%, in construction and heavy industries by 19.7%, and in the service industry by 19.0%.

The rate of inflation in the country in 2006 was 8.4%, and gross national product (GNP) in Kazakhstan in terms of current prices was up to 9,738.8 billion KZT. Growth in the volume of industrial production in 2006 was 7.0%, in agriculture – 7.0%, services of transport and communications – 20.4 %, and trade – 14.4%. Total industrial production was comprised of the mining sector (57.9%), the manufacturing industry (36.7%) and the manufacture and distribution of electric power, gas and water (5.4%). The volume of gross output of agriculture in the Republic was 7.8 billion KZT. In yield volume in the same year was 16.5 million KZT.

In 2006 growth in the quantity of cattle reached 3.8%, sheep and goats – 6.2%, pigs – 1.6%, and horses – 4.8%. There are accepted and pending mid-term programs aimed at the development of a securities market, development of a pension system and development of insurance (Figure 1).

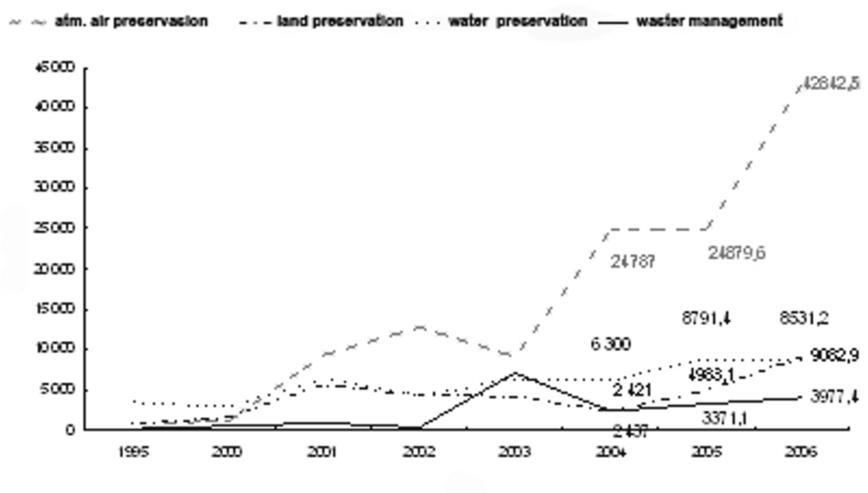

Figure 1. Dynamics of investments in environmental preservation and rational use of natural resources (in millions KZT).

2. Atmospheric pollution

In 2006, emissions of harmful substances into the air from stationary sources were 2.921 million metric tonnes. In comparison with 2005, this level decreased by 0.6% (Figure 2).

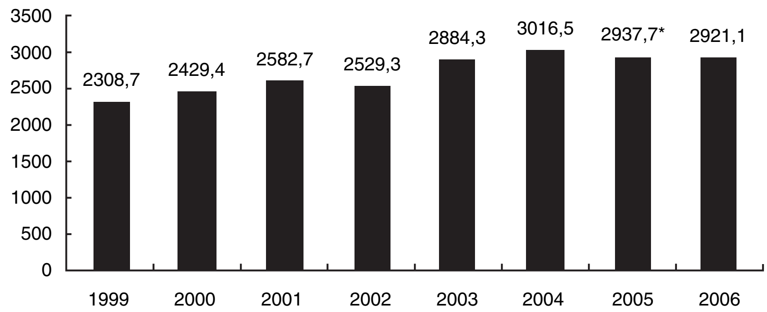

Figure 2. Dynamics of emissions of pollutants from stationary sources in 1999–2006 (in thousands of tonnes).

The majority of this atmospheric pollution comes from the industrial power, oil and gas, and municipal and agricultural sectors. During recent years due to the intensive operation of hydrocarbon mining operations emissions from mining increased. Considering this fact, environmental conditions of Atyrau, Mangystau and Aktobe oblasts have declined. According to data from the Atyrau Regional Environmental Authorities (2006), the gross volume of atmospheric pollutants emitted from static and mobile sources to the atmosphere in this region in 2006 were up to 131.1 thousand tonnes, which is on 13.1 thousand tonnes higher than in the previous year. This rise was caused by increased gas transportation volumes from the «Atyrau CJSC ITsA», as well as accidents at "Tengyzshevroil" OJSC, among others. Overall atmospheric emissions from static point sources in 2006 were up to 104.1 thousand tonnes, which is on 13.1 thousand tonnes higher than in 2005. The Table 1 below lists data on pollutant emissions from some huge point sources of Atyrau region. The majority of emissions were caused by the "Tengyzshevroil" OJSC.

In 2008 the opening of a second gas processing plant is planned at Agip KCO, which will cause oil mining to increase two times and also double the atmospheric pollution. This will, of course, have an impact on the environmental conditions in the region. In addition to the hydrocarbon mining starting at the Agip KCO, oil mining volumes on the Caspian Sea shelf are to be increased up to 100 million tonnes a year. When the exploitation of a new gas refinery plant at the Karabotan begins, the environmental situation in Atyrau will dramatically decline.

TABLE 1. Atyrauskaya oblast point source pollutant emissions (in tonnes).

Plant	2005			2006 (forecast)			"+" incr."–" decr.
	Total	Solid	Gaseous	Total	Solid	Gaseous	
"Tengyzshevroil" Ltd.	53,875.5	183.6	53,691.9	55,543.567	372,732	55,170.8	+1,668.1
Agip KCO	1,488.3	68.17	1,420.2	2,940.2	126.8	2,813.4	+1,451.9
PPh «Embamunaygas»	8,928.8	380	8,548.8	6,953.7	224.1	6,729.6	–2,199.2
"Atyrau thermal power plant" OJSC	2,594.2	8.117	2,586.13	2,495.5	24.3	2,471.1	–98.7
ANU	1,435.8	1.338	1,434.5	923.199	6.31	916.892	–512.601
"Atyrau Oil Refinery Plant" Ltd.	5,492.6	16.96	5,475.7	4,546.95	14.83	4,532.12	–945.65
«Atyrau CJSC ITsC»	11,558.7	1.8	11,556.2	19,718.4	1.39	19,717.0	+8,159.7

Total emissions volume during 2006 in Mangystau oblast (Mangystau Regional Environmental Authorities 2006) was up to 52.26 thousand tonnes, including sulphuric anhydride – 0.35 thousand tonnes and nitrogen dioxide – 7.99 thousand tonnes.

By 2006 in Mangystau oblast there were 75 oil-storage pits of 7,3158.4 tonnes total volume and a total area of oil polluted land of 1,881.5 km^2. Flare burnt gas volume at oil and gas mining plants was 216 million cubic metres. All of these components are polluting the atmosphere, soil and ground water.

3. Degradation of farmland

About 75% of the agricultural land in the Republic of Kazakhstan, which is shown in Figure 3, is under different levels of environmental destabilization risk (Land Resource Management Agency of the Republic of Kazakhstan, 2006). According to preliminary evaluation, pasture degradation, field erosion, and secondary salinization have led to financial losses of up to 300 billion KZT.

In terms of land quality characteristics, areas of soil erosion in the Republic cover 5 million hectares, where arable lands total just 1 million hectares. Wind erosion areas are over 25.5 million hectares, of which 594.6 thousand hectares are arable lands. As of November 1, 2004, of 188.9 million hectares of pasture lands under the extreme degradation, 26.6 million hectares were under strong or very strong desertification. The degradation process has a rising tendency.

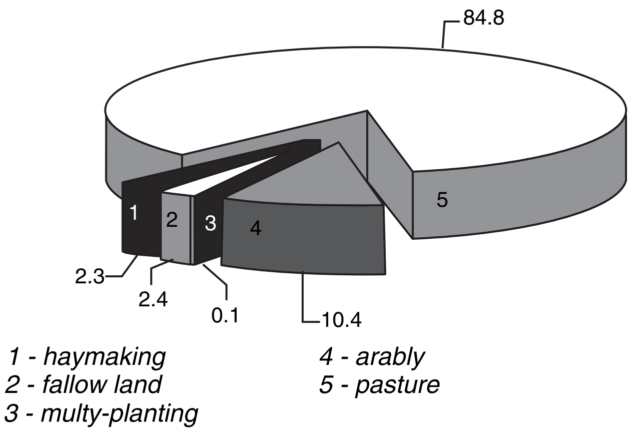

Figure 3. Structure of agricultural lands in 2006 (%).

Of the land in the Republic, 2.3648 million hectares are irrigated. These irrigated lands provide production of more than 30% of the agricultural GDP. In 1991 2.284 million hectares were used for agricultural purposes. In 2001, 1.3178 million hectares were irrigated. The rest of the 1.047 million hectares were not in use because of salinization, irrigation system damage, lack of water sources, soil ameliorative conditions and lack of material and technical resources.

4. Waste from production consumption

Total industrial waste in the Republic in 2006 was 671.24 million tonnes. Of this, Class 3 and 4 toxic waste made up 225.3 million tonnes and household waste was 12.7 million tonnes. On average, 16% of the total waste was recycled.

5. Sewage and loss of water

In 2006 in the Republic the total water supply volume was about 21.244 billion cubic metres, including surface water and ground water 20.071 billion cubic metres (Ministry of Agriculture, 2006).

As a whole, the volume of sewage dumped in superficial reservoirs has increased by 7.6%, including 3% on land and in pond-stores and 2.5% on filtration fields. According to the Republic of Kazakhstan Statistics Agency, outflow and untracked discharge of water in the Republic accounts for 17.8% of all water submitted to a network. The greatest quantity of water is lost in Atyrauskaya (45.3% of all submitted waters in the area network), Akmolinskaya (28.1%), Zhambylskaya (25.4%) oblasts, and in the cities of Almaty and Astana (38.1% and 24.7%, respectively).

In 2006 water security was estimated at 77.7%, an overall increase of 1% over 2005. The quality of water in centralized sources of water supply is mismatched in terms of specifications of microbiological (2.2%) and sanitary-chemical parameters (2.4%). Low water security remains a problem in Northern-Kazakhstan oblast-64.6% (63.2% in 2005), as well as South-Kazakhstanskaya 67.5% (65.7%), Kostanayskaya 68.4% (67.5%) and Zhambylskaya 68.2% (67.0% in 2005) oblasts. The worst sanitary-chemical and microbiological parameters of water are found in Kyzyl-Ordanskaya (9.2% and 6.4%) and Akmolinskaya (7.2% and 4.2%) oblasts. Transportation losses were 3.764 billion m^3.

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Part III

Water Resources and Effective Uses

Water shortage.

INTRODUCING WATER PRICING AMONG AGRICULTURAL PRODUCERS IN KHOREZM, UZBEKISTAN: AN ECONOMIC ANALYSIS

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Abstract. The extensive use of water in agriculture in the Amu Darya and the Syr Darya basins has led to the desiccation of the Aral Sea. The lack of water pricing in Uzbekistan does not provide incentives for local agricultural producers to improve water use efficiency. Although water pricing may decrease water intake in and increase its outflow from Khorezm to the Aral Sea, the impacts of this policy on regional consumers and agricultural producers can be random. Different rates of water prices will cause different regional cropping patterns, which will bring a new system of commodity prices and, as a result, will affect the population income and food consumption in the region. Therefore, a proper rate of water pricing should be derived and its impact on regional agriculture should be established. To this end, this policy evaluation, which is part of a wider Ph.D. research project, consists of a microeconomic analysis of agricultural reforms in Khorezm based on a sector model (KhoRASM) which reflects the unique features of the region's agriculture. The model integrates three components: (1) an agricultural sector model; (2) a linear supply module with three types of agricultural producers; and (3) a flexible demand system (Normalized Quadratic-Quadratic Expenditure System) with two types of consumers. The specific objective of this study is to provide information about possibilities of introducing water pricing such that economic efficiency of water use in the region can be improved.

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Keywords: Policy analysis, water pricing, agricultural sector, commodity demand, population income, mathematical programming

> *Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.*
>
> – The Dublin Statement on Water and Sustainable Development (1992)

1. Background

The Khorezm region is divided into two parts by the Amu Darya. The right bank of the river is approximately 230,000 ha and only slightly used for agricultural production. The left bank has an area of 455,000 ha, from which 276,000 ha can be fully irrigated and used for agriculture. The region consists of ten almost equally-sized administrative districts. As shown in Figure 1, there are river bordering districts which have immediate access to the irrigation water and off-stream districts which have no direct access to the river. The districts without direct access to the river are dependant for their water supply on the water consumption in the districts that border the Amu Darya directly (Müller, 2006).

In 2003, the population in Khorezm was over 1.4 million people, and constituted about 5.5% of Uzbekistan's total population. The labor force amounted to 52% of the region's total population. The share of the rural population increased from 74.6% in 1992 to 77.2% in 2003. The average arable area per capita in the region was 0.2 ha. Although the total population in Khorezm grew steadily in the period between 1992 and 2003, the annual regional growth rate declined from 3.1% in 1992 to 1.4% in 2003.

The regional GDP per capita in 2003 was about US$255. The agricultural sector accounted for roughly 67% of the total regional GDP in 2003. Crop production amounted to 43% and the animal sector produced almost 56% of the agricultural sector's total output in 2003 (OblStat, 2004a). According to the state procurement system, the regional land allocation is determined primarily by the government and the state procurement quota. Remaining arable land may then be allotted to other crops at the discretion of agricultural producers. Consequently, with the intensification of the farm restructuring process, the land allocated under cash crops has not increased. In 2003,

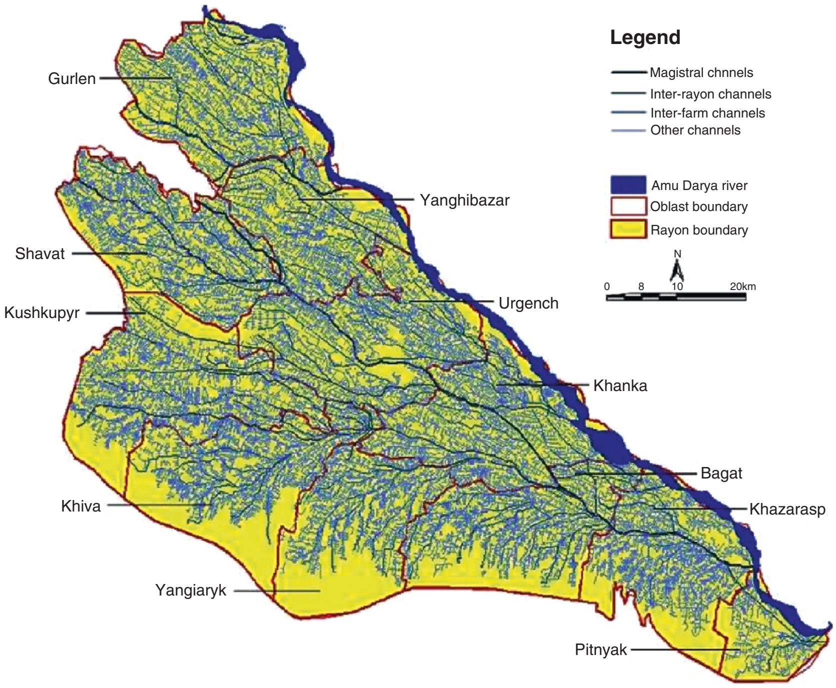

Figure 1. Map of Khorezm region.

Source: GIS Lab of ZEF/UNESCO project, Urgench, 2005.

80% of the crop area in Khorezm was sown with cotton, wheat and rice. The production of other crops such as maize, potato, vegetables, melons, and fodder crops was less significant as they covered only 18% of the total crop area. The reforms, which were developed to achieve both a transition to a market economy and grain self-sufficiency, changed the cropping pattern in Khorezm considerably (Table 1). Five major observations regarding the regional cropping pattern can be made for 1993–2003: (1) the cotton cultivated area has been kept unchanged; (2) the area under cultivation of food crops, especially winter wheat, increased dramatically; (3) the increase in wheat area was achieved at the expense of annual fodder crops such as fodder maize and (4) at the expense of perennial crops in particular lucerne production; (5) there was an attempt to introduce new crops into the regions' production system, including sugar beets in 1998–2001. Except for the drought period in 2000 and 2001, the total regional crop area has increased steadily.

TABLE 1. Cropping pattern in Khorezm.

Crops	Sown area, 10^3 hectares													Share in national production %
	91	92	93	94	95	96	97	98	99	00	01	02	03	
CTN	105,6	107,0	112,6	102,9	102,1	100,9	100,3	100,6	100,3	95,9	109,6	110,7	102,3 [1]	6,1
WWT	3,9	6,3	4,2	12,8	16,9	33,6	27,0	31,0	30,5	30,7	36,0	46,3	50,7 [2]	3,4
RCE	28,1	30,8	32,1	32,1	38,2	47,9	47,0	41,8	39,9	31,7	9,8	19,1	30,6	32,3
PTT	1,7	1,7	1,9	1,8	3,1	2,9	2,6	2,2	2,2	2,3	2,7	2,6	2,9	4,1
VGL	8,6	9,3	8,2	8,4	9,6	6,8	6,5	6,5	5,7	6,1	7,1	7,9	8,7	5,1
MLN	22,3	21,4	19,7	19,3	18,7	17,6	21,8	17,3	14,1	13,7	15,5	16,0	15,6	6,7
MZE	3,1	2,8	3,7	1,7	7,3	2,4	3,0	2,1	2,0	1,5	1,3	1,2	1,0	2,1
FOD	46,0	42,9	42,7	43,3	35,9	25,5	31,7	25,9	24,1	21,6	17,7	22,3	20,1 [3]	8,3
OTH	15,0	12,6	9,8	15,5	5,6	3,1 [4]	0,1	11,7	19,0	20,2	11,2 [5]	0,3	0,2	1,6
TSA	234,3	234,8	234,9	237,8	237,4	240,7	240,0	239,1	237,8	223,7	210,9	226,4	232,1	6,1

CTN – Cotton; WWT – Winter wheat; RCE – Paddy rice; PTT – Potato; VGL – Vegetables; MLN – Melons; MZE – Maize for grains; FOD – Maize for fodder and annual grass; OTH – Other crops, incl. lucerne, sugar beet and sunflower; TSA – Total sown area.

Sources: OblStat, 2004a; FAO, 2007.

In 2003, the output of the agricultural sector per hectare of sown area was about US$1,044. The distribution of products varied depending on the type of agricultural producer. While large state farms (*shirkats*) and private farms were specialized in producing cotton and grains, households dominated in production of horticultural crops. According to official statistics (OblStat, 2004a), shirkats occupied about 56% of total sown area and produced 22% of total output of the agricultural sector. Private farms occupied 30% of sown area and produced 10% of total agricultural output. Households occupied 14% of total sown area and produced about 68% of total agricultural output in 2003.

According to primary estimations provided by the official statistical bulletin, annual regional income of the population was about US$224 million in 2003 (OblStat, 2004b), or US$159 per capita. In 2003, the total expenditures of population in Khorezm was about US$192 million (OblStat, 2004b), or US$136 per capita. The total expenditures for food and non-food in Khorezm in 2003 were about US$76.6 million, from which 87.8% were spent for food consumption purposes (OblStat, 2004b). Between 1992 and 2003 the actual share of total value of food expenditures in total expenditures for Khorezm was on average 81.6% (OblStat, 2004b). Foreign trade turnover in 2003 was about US$48 million, from which export accounted for 74%. Cotton was the dominant item of regional export (81.4%) and the overall regional trade balance (61%) in 2003 (OblStat, 2004b). In 2003 the region was still a net importer of food commodities (35% of total import). Rice and vegetables were the only food crops produced in surplus in Khorezm (Table 2). The highest share of calories among all food commodities belongs to wheat and other grains (except rice and maize) which are crops produced in deficit in Khorezm. In addition to wheat and grains, potatoes, fruits and melons were the food commodities imported into Khorezm in 2003.

TABLE 2. Agricultural commodity production and consumption in Khorezm in 2003.

Crops	Production	Food consumption	Animal Feeding	Export	Import	Share in Food expenditure	Calorie share
	10^3 t	10^3 t	10^3 t	10^3 t	10^3 t	%	%
CTN	152,9	-	-	152,9	-	-	-
WWT	185,8	249,8	-	-	64,0	10,6	57,5
RCE	119,0	19,5	-	99,5	-	2,3	3,8
PTT	39,6	42,4	-	-	2,8	3,1	2,4
VGL	164,0	72,5	-	91,5	-	10,7	2,3
MLN	115,3	132,3	-	-	17,0	13,9	2,5
MZE	2,8	-	14,4	-	11,6	-	-
FOD	212,3	-	694,4	-	482,1	-	-

CTN – Cotton; WWT – Winter wheat; RCE – Paddy rice; PTT – Potato; VGL – Vegetables; MLN – Melons; MZE – Maize for grain; FOD – Fodder maize and annual grass.

Sources: OblStat, 2004a; FAO, 2007.

2. Water use

Given the low level of precipitation, water from the Amu Darya is the only source for irrigation and agricultural production in Khorezm. Water from the river is channeled to agricultural fields by gravity through a hierarchically arranged irrigation network – including main, inter-farm, and on-farm channels (Khamzina, 2006). The total length of irrigation canals in Khorezm is about 15,987.5 km, from which 2,371.5 km are inter-farm canals and 13,616 km are intra-farm canals (Abdolniyozov, 2000). The total length of drainage canals in the region is about 10,500 km from which 3,700 km are inter-farm and 6,800 km are intra-farm drainage canals (OblSelVodKhoz, 2002). The water arriving in Khorezm is collected in the Tuyamuyun reservoir, and its volume is rationed depending on the monthly water demand in the region. Annually, there are two distinct cycles of water use in agriculture (Figure 2). The first cycle covers the period from February to March, in which water is used for flushing salts from the top soil, i.e., the leaching period. Leaching is undertaken on 80–85% of irrigated area (Abdolniyozov, 2000). The second cycle covers May–September; i.e., the main crop vegetation period.

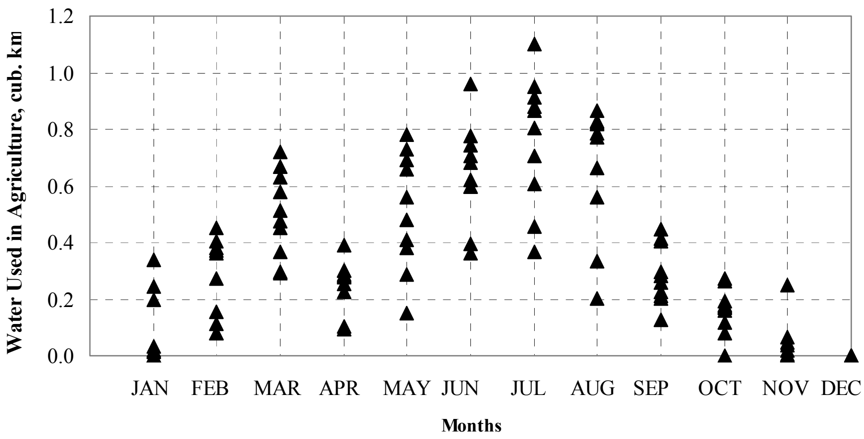

Figure 2. Monthly water use in Khorezm.

Source: OblSelVodKhoz, 2004a.

Water is intensively applied in crop production in Khorezm. First of all, the local recommendation (norms) established by state agencies on water application for crops exceeds the values calculated by CROPWAT[1]; irrigation norms for winter wheat and potato are about 40–60% higher than the CROPWAT estimates (WARMAP, 1996). The water requirements for other crops, except cotton and early maize for grains, are 9–28% higher than the CROPWAT estimates. Second, since the water is delivered free off charge, there is a lack of incentive to apply it efficiently, especially in districts bordering with the river. The most water intensive cropping activity in Khorezm is rice cultivation with 26,200 m^3 of water per hectare recommended only for irrigation, while some researchers reported about 40,000 m^3/ha (Kyle and Chabot, 1997). Despite being cultivated on about 13.2% of sown area in 2003, rice required about 44.9% of total crop water demand (Figure 3).

Additionally, the average amount of water used during the irrigation period is about 14,100 m^3/ha and for leaching is about 5,200 $m^{3/}$ha (Abdolniyozov, 2000). Although water use per capita has decreased in the last 10 years in Khorezm, per hectare consumption has remained unchanged. Additionally, the total output of one cubic meter of used water has been increasing and, in general, water inflow into Khorezm meets the demand

[1] CROPWAT is a decision support system developed by the Land and Water Development Division of FAO.

http://www.sdnbd.org/sdi/issues/agriculture/database/CROPWAT.htm

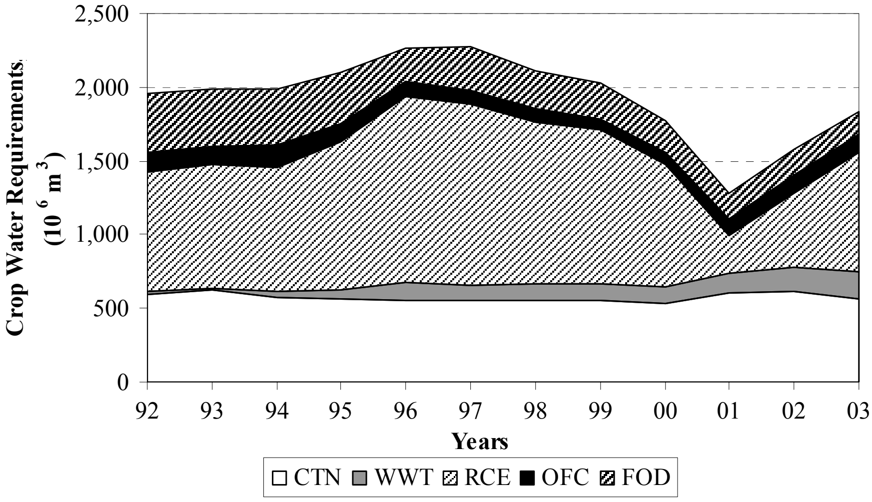

Figure 3. Crop water demand in Khorezm.

CTN – Cotton; WWT – Winter wheat; RCE – Paddy rice; OFC – other food crops; FOD – Fodder crops.

Source: OblSelVodKhoz, 2004a.

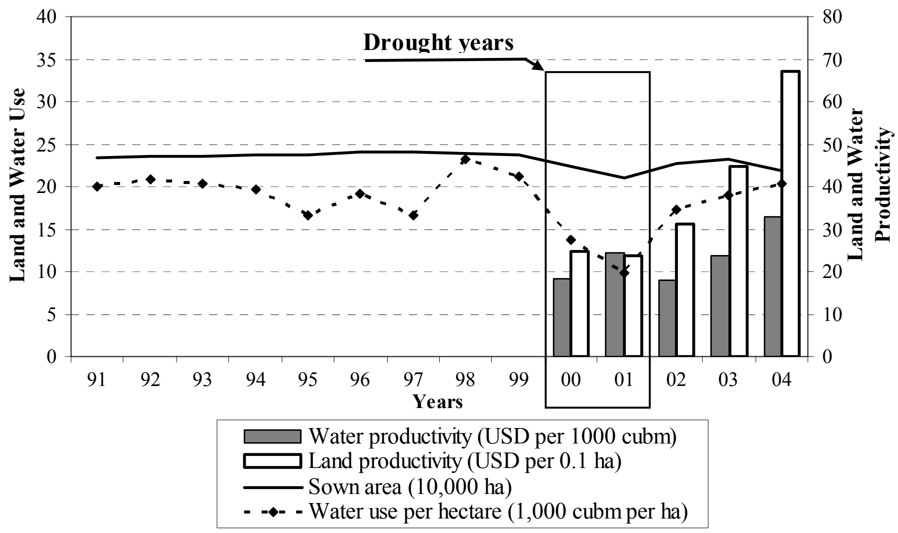

Figure 4. Dynamics of land and water use and productivity in Khorezm.

Sources: OblSelVodKhoz, 2004a; OblStat, 2004b.

(Müller, 2006). However, in the period of 2000–2001 the region experienced water shortages (Figure 4). The likelihood of water-shortages in Khorezm has definitely increased such that the probability of obtaining sufficient amounts of water fell from 82% in 1992 to 74% in 1999. Thus, based on the observed conditions of 1999, there can be 3 drought years on average in a decade (Müller, 2006).

The central problems in agriculture of the Khorezm region are those related to the extensive irrigation and drainage network (Kyle and Chabot, 1997). These problems include inefficiencies in the irrigation system, drainage, field canals and field application (Purcell and Currey, 2003), which effectively decreased water supply for agriculture. The irrigation and drainage canals have been operated without rehabilitation and modernization for more than 30 years (Abdullaev, 2003), and require maintenance to remove sediment and weeds from the beds and sides (Forkutsa, 2006). The current budget expenditures for operation and maintenance (O&M) can be characterized as unsustainable, i.e., the amount of budgeted funds available for investing in canal system is lower than required. Due to the extension of the irrigation system between 1995 and 2001, the yearly amount of budget expenditures for O&M in Uzbekistan has been declining since 1998 (Table 3).

TABLE 3. Operating and maintenance costs in Uzbekistan.

O&M Costs	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**
O&M costs per irrigated area (USD ha^{-1})	81	131	104	127	122	87	75	54	56
O&M costs per canal system (USD km^{-1})	979	1,613	1,258	1,540	1,475	1,017	829	603	641
O&M costs per irrigation water (USD 1000 $cub.m^{-1}$)	6.1	9.6	7.1	8.6	7.7	6.8	7,4*	3,5**	3,8**

Sources: MAWR, 2004c; Müller, 2006.
*Based on water inflow data from Müller (2006).
**Based on average water inflow in Uzbekistan in 1995–1999 from MAWR, 2004c.

The poor condition of irrigation canals causes a loss of about 63% of the river water diverted for irrigation in Khorezm before it reaches the fields (FAO, 1997). According to Abdolniyozov (2000), the efficiency coefficient of the main irrigation channels in Khorezm is 0.9–0.96. The efficiency coefficient of intra-farm channels is 0.7. Local authorities claim that the field application efficiency varies in the range of 55–60%; 62–73% efficiency has been quoted in country reports (WARMAP, 1996). However, according to WARMAP (1996) the field application efficiency can be lower – around 40%.[2] The entire irrigation network has a coefficient of efficiency of 0.50–0.55; meaning that 44–45% of irrigation water is lost into the drainage

[2] The annual water application in Khorezm can be greater than 50,000 cubic meters per hectare in the case of irrigation of rice fields (Kyle and Chabot 1997).

system (Abdolniyozov, 2000). Additionally, adequate drainage is not ensured due to the average length of drainage canals, which is only 37 m/ha, while it should be 50 m/ha (Kyle and Chabot, 1997). All these have been causing problems with salinization of the soil and shallow groundwater table in Khorezm (Kyle and Chabot 1997; Forkutsa, 2006). Because of high salinity of soil and ground water, water losses in irrigation canals in Khorezm become 'real' unusable losses (WARMAP, 1996). Given the canal installation costs, it seems clear that the best approach at present is maintenance and rehabilitation of the existing system (Kyle and Chabot, 1997).

3. Water pricing

As world practice shows, the introduction of water prices can increase water productivity via investments of the collected water charges into series of agronomic, technical, managerial and institutional improvements, such as clean supply and drainage systems, and accurate irrigation schedules (Dinar and Latey, 1991; Wallace and Batchelor, 1997; Kyle and Chabot, 1997; Batchelor, 1999). Consequently, implementation of water pricing can improve water use efficiency[3] (WUE) and crop yields. Although WUE is related to water productivity at the system level, and the crop yield effect is related to water productivity at the agricultural producer level, both measures are interlinked. WUE improvement refers to technical efficiency, specifically the efficiency of water distribution systems, resulting from a minimization of water losses and adequate quantity of irrigation water at the right time. The efficiency of water-use by agricultural producers can be increased via timely supply of irrigation water at particular stages of crop development when crop response to irrigation is highest. Next, the rules of distribution of water among different locations can be improved by providing better incentives to agricultural producers to reduce their irrigation costs. Water pricing can similarly provide appropriate incentives for agricultural producers to increase crop yields in order to recover the values of crop gross-margins. Likewise, water pricing may help mitigate water scarcity problems that increasingly pose a major impediment to growth and development in districts which do not border the Amu Darya.

Cost recovery, performance deterioration of irrigation and drainage systems, and water scarcity are the main factors motivating the introduction

[3] Water use efficiency is related to water use in crop production and has the same meaning as Gross Production Water Use Index, which is expressed in terms of total or harvested portion of the crop produced per unit of total water applied (NPRID, 1999). The volume of water applied includes both leaching and irrigation.

of water pricing for agricultural producers in Uzbekistan. Since 1998, following the farm restructuring process, the state policy on the O&M of the irrigation and drainage systems has been reconsidered. In the preliminary stage of water reforms, the management of irrigation and drainage systems in Khorezm was transferred from state agents to public suppliers, i.e., water user associations (WUA). In order to ensure that the costs incurred by WUAs are fully or partially covered by agricultural producers, the latter will be charged for water via membership fees and payments for provided services. However, the institutional changes in Uzbekistan, such as establishment of WUA's, were only made in name, rather than in practice. Water pricing still remains at the stage of statement of intent.

Due to the features of Khorezm, the introduction of water pricing has a special meaning for regional agriculture, which fully depends on irrigation. First, water scarcity constrains regional agricultural production (Müller, 2006). Second, the water distribution system in Khorezm results in low water productivity, causing high distribution and conveyance losses. Improvement of the system requires large investments (Abdolniyozov, 2000). Third, the current institutional controls governing water use in Uzbekistan do not encourage agricultural producers to use water efficiently; after independence, water charges in agriculture were not introduced and expenditures for irrigation are still covered by the state budget. In this context, there is a need to attain a more efficient and productive use of water in the agricultural sector, which can be achieved via the introduction of water charges for agricultural producers (Tsur et al., 2004).

However, water charges should not be introduced without sufficient research into their impacts. The analysis of new historically unobservable external shocks should be carried out by developing a proper model. This model will help to understand how water pricing designed to achieve full cost recovery would affect producers' income, land and labor use in farms, crop production and consumption.

4. Research description

This study is part of a development research project on economic and ecological restructuring of land and water use in the Khorezm region. One of the objectives of the project is to develop concepts for landscape restructuring in Khorezm with proposals for legal-administrative and ecological restructuring measures using sustainable natural resource management concepts. As part of the project the overall goal of this study was to analyze the consequences of different agricultural policies on regional production and consumption patterns. The following analysis was conducted in three steps. In the first stage, the collection of relevant publications and literature on agricultural production in Khorezm and Uzbekistan was conducted. In the second stage, primary data were collected via farm and household surveys, and secondary data was gathered from official statistical departments. Finally, impacts of different policy options on regional production and consumption were identified and analyzed. Therefore, in order to formalize the major aspects of sectoral decision making, a mathematical programming model was developed that reflects the unique features of the agricultural sector of Khorezm.

4.1. MODEL

The agricultural sector model for Khorezm (KhoRASM) is designed according to the framework presented by Hazel and Norton (1986) for evaluating the impact of external shocks on production and consumption patterns and commodity prices. KhoRASM is a static model, and assumes that the adaptation of the agricultural sector to intervention occurs without a time lag. KhoRASM is a partial equilibrium model, which means that explicit connections to other sectors of the general economy are not included. In the base run solution, KhoRASM replicated the agricultural production activities of Khorezm in 2003. To simplify the features of the regional agricultural sector of Khorezm, several assumptions for the model were formulated as follows:

- The model is a partial equilibrium model, maximizing consumer and producer surplus.
- The region is small enough to affect national commodity prices.
- Products within each commodity type are homogeneous.
- Commodity consumption is determined by commodity prices and income.
- Relationships between inputs and outputs are linear in the form of single Leontieff technologies.

The model integrates three components: (1) an agricultural sector model; (2) a linear supply module with three types of agricultural producers; and (3) flexible demand systems (Normalized Quadratic-Quadratic Expenditure System as presented in Frohberg and Winter (2001)) with two groups of consumers (Figure 5). Consequently, the model optimizes via simultaneous adjustments in supply and demand sides, which will be presented separately in the following sections of this paper. The supply module includes all the input and output items of the crop, animal and fodder sectors. The demand module consists of food consumption by the regional population. Each of the supply and demand modules is divided into several production and consumption blocks with regard to producer, consumer and district aggregates.

The behavior of producers in the supply module is depicted at an aggregate level and restricted in terms of initial resource endowments, while the behavior of consumers in the demand module is depicted via commodity demand functions.

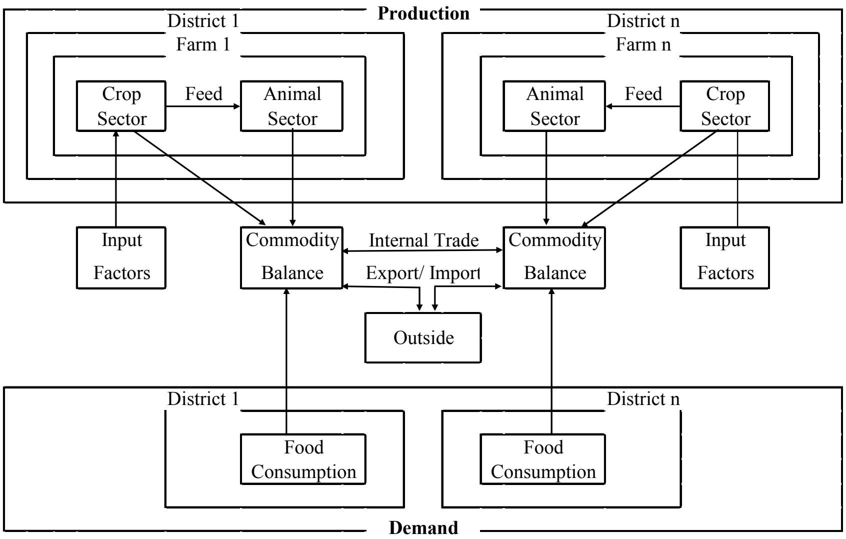

Figure 5. Structure of KhoRASM.

Source: Author's representation.

For reasons of computational necessity and data needs, the model's demand and supply sides are aggregated over districts, producers, consumers and commodities. In the model, the region is separated into 10 administrative district aggregates (Figure 1).[4] Each district is described by its resource endowments and technology coefficients. Following Hazell and Norton (1986) the production module includes three different submodels to represent the main agricultural producer aggregates defined by Uzbek legislation, i.e., rural households (*dekhqans*), private farms, and large agricultural enterprises (*shirkats*). This type of aggregation makes procedural sense, especially since official statistical data for production patterns and input endowments are available only at this level of aggregation.

Analogous to the agricultural producers, the consumers are also aggregated into separate groups: The rural household aggregate is included into the group of consumers of food and non-food commodities and leisure. In

[4] The model used in this paper is an updated version of KhoRASM. The original version of KhoRASM uses five district aggregates.

addition to the rural households, the urban households are introduced as consumers. KhoRASM consists of commodity aggregate production and consumption in the region and transportation within or outside of the region. The model includes 14 commodity aggregates which can be produced, consumed, traded or used for animal feeding. The consumed commodities include food commodities produced in Khorezm, other food commodities imported from outside of the region, manufactured (non-food) commodities and leisure.

A large amount of data is required for sector models (McCarl and Spreen, 1980). In this study, data from a private farm survey in 2003 and household survey in 2004 were used, as well as secondary data acquired from official governmental agencies. Altogether 356 private farms and 400 households were interviewed. Due to the lack of data on regional consumption patterns, the information on consumption in Uzbekistan for 2003 was taken from the Supply Utilization Accounts (SUA) and Food Balance Sheets (FBS) in the FAO Statistics Division.[5] The primary (uncalibrated) values used for the demand elasticities are the values obtained from the WATSIM[6] model's base-run dataset on the rest of the world.

To ensure that the base solution of the model fits the observed values of modeled activities and to ensure that the model simulations include the characteristics of regional demand and supply, the model parameters both for demand and supply sides were adjusted. In this scope the model contributes to methodology via application of a new calibration approach alternative to Positive Mathematical Programming. Finally, using a calibrated version of the model, different simulations of agricultural policies were made and their impacts on regional supply and demand were discussed. Results obtained after implementing an exogenous shock in the model are compared with the base run results. The KhoRASM model is programmed using the GAMS modeling language; it was then calibrated and solved as a non-linear optimization, using the numerical solver CONOPT3.

5. Selection of water pricing method

Selecting a method for water pricing was governed by concerns for water conservation and equity. First, in setting an appropriate price for water, care must be taken to ensure that water scarcity areas are not prevented from

[5] No commodity price information for Uzbekistan was available in the database of FAO Statistical Division by 02.02.2007.

[6] The WATSIM is a recursive-dynamic spatial world trade model for agricultural commodities. It is mainly applied for the medium-term analysis of trade policy changes (Kuhn, 2003).

meeting their irrigation water demand. Second, the water policy should be set such as to protect the poor, e.g., a 'free' allowance of irrigation water to rural households, with payments only for cash crops such as rice. Next, a cross-subsidy principle between those unable to pay and those with greater means should be taken into account. Finally, the price must ensure a synergy between water pricing and agricultural policy, such as subsidies for cotton production.

There are two mechanisms for water charging, including volumetric and non-volumetric methods; both have advantages and disadvantages depending on the situation under consideration (Tsur et al., 2004). Prior to the model adaptation, the appropriate method of water charging for the agricultural sector in Khorezm was selected by studying literature on main features of volumetric and non-volumetric area-based methods.

A volumetric water charge is the most obvious and widely studied economic instrument used to assign a price to water, thereby making the water charge a direct function of the quantity supplied (Hellegers and Perry, 2004). The main requirement of this method is the regular information on the quantity of water used by each agricultural producer below the measuring point (Dinar et al., 1997). In theory, volumetric pricing can lead to an efficient allocation, but this method was rarely applied successfully due to several problems which also make the introduction of volumetric water pricing in Khorezm less attractive.

The first problem of applying the volumetric pricing mechanism is absence of facilities for accurate and regular volumetric measurement of supply and use of water in Khorezm. The installation and administration of such facilities are expensive in the case of a large number of individual water users.

The second problem is related to the policy of state-controlled cropping according to which irrigation of cotton during the vegetation season is decided by local administration, rather than by agricultural producers.

The third problem with this mechanism is related to the fact that volumetric methods ignore equity concerns and the pricing of water is not the same among different types of agricultural producers (Tsur et al., 2004).

The fourth problem is that in temporal dimensions, the water charge value can be equal to zero when it is not needed by agricultural producers or during the periods of excess water availability, such as flood months.

Finally, in a spatial dimension, the districts with water scarcity will pay the highest price for water, and the districts bordering with the Amu Darya, i.e., with abundant water, will pay the lowest water price.

The non-volumetric mechanism of water charging is often applied in cases with a large number of water users and in cases where there is inadequate information about actual volumes of water supply and demand

(Tsur et al., 2004). The main advantage of this mechanism is that it generates a predictable revenue stream to recover the O&M costs to water suppliers. The most applied nonvolumetric method is area and crop based charging mechanisms according to which charges are fixed per hectare depending on the relative crop water requirements and the benefit agricultural producers get from the crops (Hamdy, 2002). In this case, water charges per hectare can be established at higher rates for cash crops, like paddy rice and vegetables in Khorezm. Prices for water may also be kept at low rates for the production of staple foods for small-scale household producers (Prathapar et al., 2001). In order to consider the equity of income distribution over time, space and agricultural producer groups, the water charges can be disaggregated by seasons, producer types and producer location (Tsur et al., 2004).

6. Model adaptation

The supply module of KhoRASM was simulated for the base run conditions in order to obtain the distribution of shadow prices among modeled districts and water use seasons. Based on the distribution of the shadow prices (Figure 6), the base water price was selected. The selected water price rate is US$15/1,000 m^3 of water, which is comparable prices established in agricultural sectors of Morocco in 2003 (Chohin-Kuper et al., 2003), and Namibia, Algeria, Tunisia, Brazil, Portugal, United States, Greece and Spain (Dinar and Subramanian, 1997) in 1996.

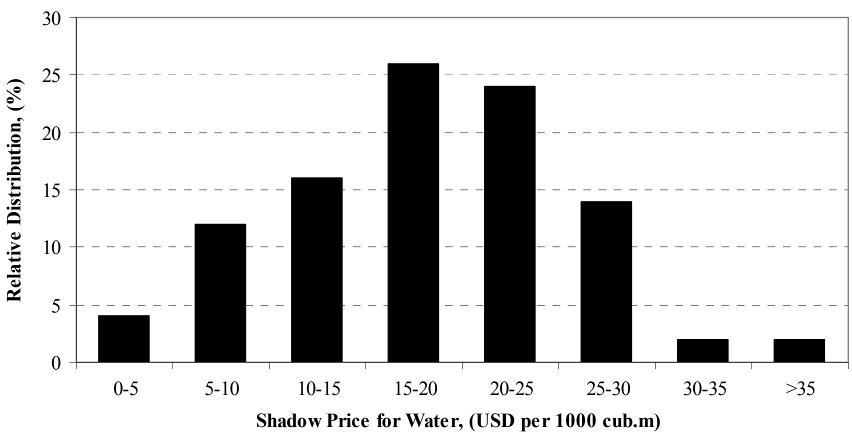

Figure 6. Distribution of shadow prices for water.

Source: Base Run of Supply Module of KhoRASM.

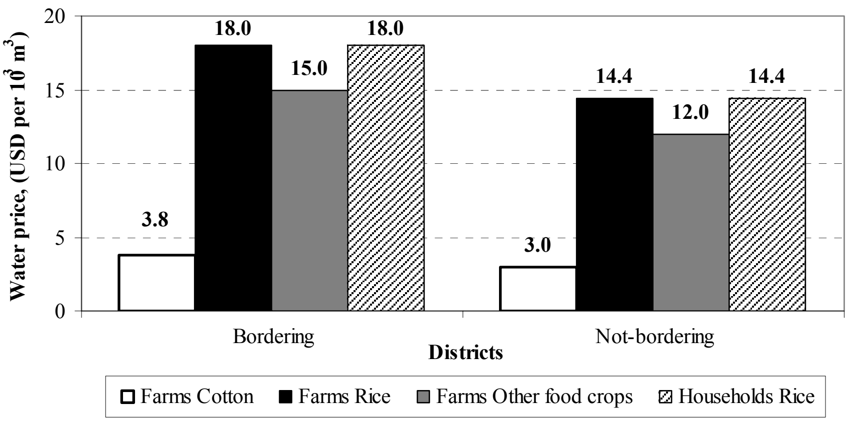

Figure 7. Location, producer and crop variations in water pricing rates.

Source: Author's representation.

Considering the pros and cons of each mechanism, the method of water charging selected for the model simulation is the crop-area-based method. In order to include the concepts of water saving and equity, the value of water charge in KhoRASM is defined as shown in Figure 7. The producers in districts which do not border with the river are charged at 20% lower rates for all crops. Food crops such as grains (except paddy rice), potato, vegetables, and melons are charged at the base value of water price. Since cotton production in Uzbekistan is subsidized, the amount of the water charge is only a quarter of the selected value for cotton. The production of paddy rice in all types of agricultural producers in upstream districts is charged at a 20% higher rate. The water used for fodder production in all district and producer aggregates is not charged. The irrigation of potatoes, vegetables, and melons in attached plots of rural households *(dekhqan* farms) is independent from the conditions of irrigation and drainage networks, as the crops are irrigated via pumping ground water. Therefore, according to a cross-subsidy principle, the water used for crop production in households is not charged, except for rice cultivation.

In the simulation, the value for water charge is assigned to the official leaching and irrigation recommendations (norms) for crops, developed by research institutes for Khorezm. In the model, the improvement in WUE is simulated by decreasing the original values of technology coefficients of actual crop water requirements by 10%. The WUE and crop yield increase (10%) depends on the water charging rules specified for crops, producers and location. Given the input prices and input application rates as observed in 2003, two crops had negative gross margins (Table 4).

TABLE 4. Land and water use and gross margins in Khorezm in 2003.

Crops	Average regional yield	Sown area	Water used	Irrigation norm	Gross margins (GM)	GM with water pricing (*ceteris paribus*)	Share of water charges in output value
	t ha^{-1}	%	%	m^3 ha^{-1}	USD ha^{-1}	USD ha^{-1}	%
CTN	1.6	44.1	31.7	5,533	-73	-94	6.1
WWT	3.6	22.1	10.3	3,600	96	69	6.5
RCE	4.4	13.2	44.9	26,200	1,078	606	30.8
PTT	13.5	1.2	1.4	8,650	913	783	6.4
VGL	19.4	3.7	4.2	8,650	813	683	6.1
MLN	15.1	1.4	0.7	3,933	486	427	6.0
MZE	3.3	0.4	0.3	5,900	157	69	24.5
FOD	14.1	8.8	6.4	5,600	-4	-4	0.0
KHO	4.7	95.0	96.5	7,975	190	100	14.9

CTN – Cotton; WWT – Winter wheat; RCE – Paddy rice; PTT – Potato; VGL – Vegetables; MLN – Melons; MZE – Maize for grains; FOD – Maize for fodder and annual grass; KHO – Khorezm region.

Sources: OblStat, 2004a; OblSelVodHoz, 2004b; Private Farm Survey, 2003; Household Survey, 2004.

The dominant crop in Khorezm (approximately 44% of sown area in 2003), cotton, had a negative gross margin of -US$73/ha in 2003. The main fodder crops produced in Khorezm, i.e., maize for silos and annual grass (about 8.7 % of total sown area in 2003), had a gross margin of -US$4/ha. Winter wheat, the second dominant crop in Khorezm (approx. 22% of sown area in 2003), had a positive gross margin of US$96/ha. The crops with highest gross-margins were paddy rice, potatoes, vegetables and melons, which occupied about 18.4% of sown area in Khorezm in 2003 (see Table 4). The introduced water charges have affected rice and maize producers the most. The value of water fees per hectare under selected water price exceeds the budget expenditures for O&M. Consequently, the water reform under selected water pricing rates can be characterized as the transition from an unsustainable to sustainable cost recovery policy.

While some may argue that the value of the water charge is too high, Hussain (2004) listed effects of low water charges which include lack of funds and incentives for water suppliers to improve on service delivery, poor maintenance of the irrigation network, and lack of incentives for agricultural producers to use water efficiently.

7. Model results

Due to the large amount of information generated in such an analysis, only the most interesting simulation outcomes are reported here in aggregated forms. The results of the water pricing show that under the given assumptions, water pricing shifted the regional cropping pattern towards the least water demanding crop. The total production of rice, the most water intensive crop in the region, decreased (Figure 8). Additionally, production of most crops decreased, leading to the drop in sown area. Since the non-volumetric water pricing method can be compared to land taxes weighted according to cropping activity, the regional welfare, including both consumer and producer surpluses, was decreased. However, the decrease in the volume of water used water can be compared to the increase in water outflow outside of the region. The decrease in land use caused a large discharge of labor from the agricultural sector, leading to the decrease of income of rural households (*dekhqan* farms).

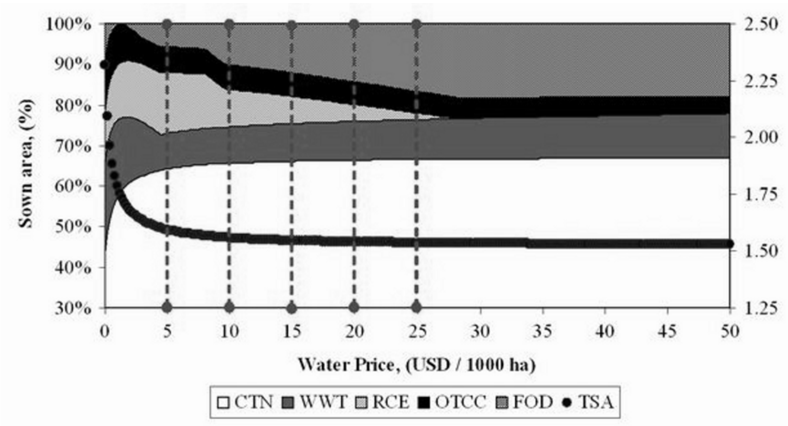

Figure 8. Regional cropping pattern.

CTN – Cotton; WWT – Winter wheat; RCE – Rice; FOD – Fodder crops; TSA – Total sown area.

Source: KhoRASM model simulations.

Rural household producers remained the dominant suppliers of food crops and animal products. The large state farms and private farms were shown to have shifted their cropping pattern towards fodder crops, the largest share of which was imported in 2003.

In the spatial dimension, a decrease in output per hectare in monetary terms was observed in the districts bordering the river (Figure 9). The most significant decrease was observed in the district which had the highest share of land allocated under rice cultivation. Since the simulation considers the equity principle, the highest payments for water are observed also in districts which border with the river (Figure 10). The shift to the cropping pattern which is less water demanding has affected most the regions bordering with the river (Figure 11).

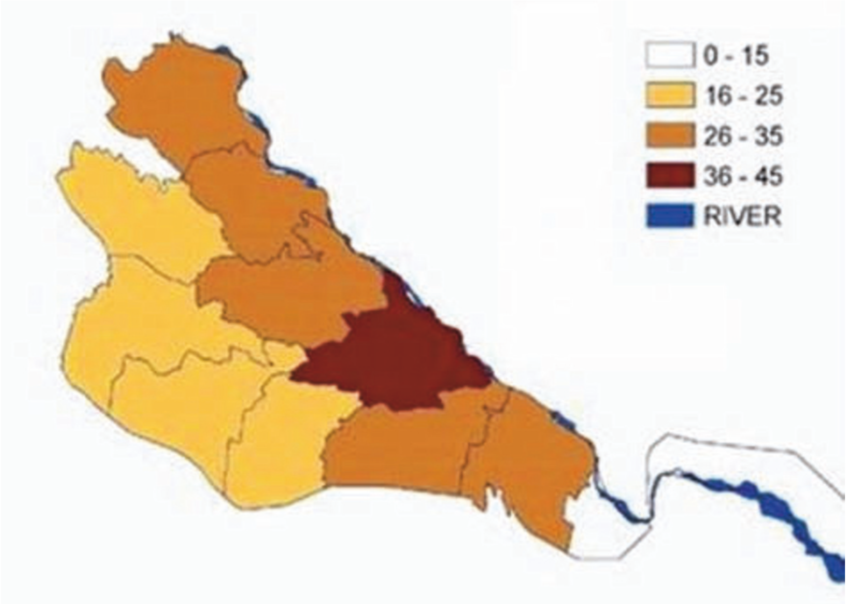

Figure 9. Output per hectare (%).

Source: KoRASM model simulations.

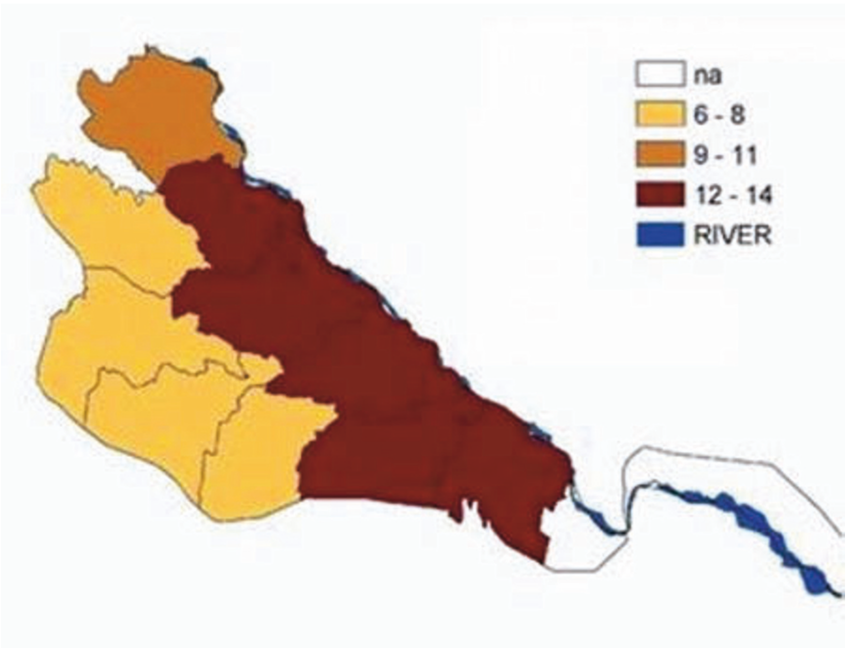

Figure 10. Payments (US$10/ha).

Source: KoRASM model simulations.

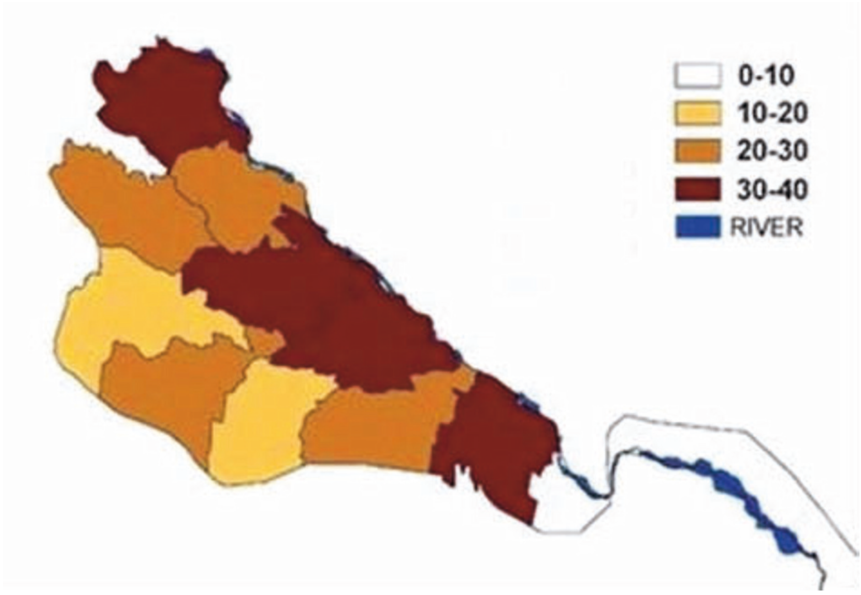

Figure 11. Water use per hectare (%).

Source: KoRASM model simulations.

8. Conclusion

The paper compares the impact of introducing water pricing in the agricultural sector of Khorezm. The analysis in the paper is based on very simplified assumptions. Therefore, the simulation results should be treated with caution. Nevertheless, it is believed that these results are solid enough to contribute to the discussion on how the simulated policy could affect the regional production and water use.

The analysis presented in this paper suggests that the introduction of water charging as a single policy will decrease the regional welfare and regional production levels. Nevertheless, the model is comparatively static and the negative welfare effects of water pricing may well turn positive if long-term effects would be taken into account, such as investments into water productivity and positive environmental effects.

Second, following the presented rules of introducing the water charging mechanism in the Khorezm region, the concept of equality in water use with respect to the district location and producer type will be held, such as the share of downstream districts and by households. In total, regional water use will not decrease. Therefore, the costs of alternative water pricing methods should be considered and the magnitudes of the social losses from inefficient pricing should be calculated to see whether water pricing methods would actually increase social welfare. Also, the water pricing changes should be made gradually over a period of time to allow the water users to adjust to the higher prices.

Third, the water pricing policies must be combined with other measures in order to solve the qualitative and quantitative water resource management problems in the region. Policies must ensure an improved synergy between water pricing and existing agricultural policies, such as subsidies for cotton production. Additionally, actions should be taken to improve some aspect of water supply service during the period of transition to water pricing to demonstrate to water users that payments for water will translate into additional benefits. In setting an appropriate price for water, care must be taken to ensure that the districts located farthest from the river are not prevented from meeting their irrigation needs.

Finally, water policies should protect the poor, e.g., a 'free' allowance of irrigation water to rural households, with payments only for cash crops such as rice. This can be achieved by introducing a cross-subsidy principle between those unable to pay and those with greater means.

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Agricultural land in the Khorezm Region, Uzbekistan.

WATER SCARCITY IMPACTS ON NORTHERN CYPRUS AND ALTERNATIVE MITIGATION STRATEGIES

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Abstract. Water scarcity on Northern Cyprus started in the 1960s and continued thereafter, prompting several studies and research to identify levels of water deficiency on the whole island. The backbone of the country's economy is agriculture, and mostly small-scale farming is practiced. Citrus fruit cultivation produces the majority of exports from Northern Cyprus. Hence, irrigation plays a great role in achieving efficient yields of these fruits. In 1997, the General Directorate of the State Hydraulic Works of Turkey (DSI) prepared a report for the Guzelyurt area. Uncontrolled irrigation of the fields, delayed replacement of old irrigation techniques with modern ones, and poor conveyance efficiency of municipal pipelines and network systems caused over-abstraction of water from available aquifers. This phenomenon resulted in higher levels of salt contamination due to salt-water intrusion in the coastal aquifers. In this study, economic, environmental, and social impacts of water problems on Northern Cyprus are examined and discussed.

Keywords: Northern Cyprus, water scarcity, alternative formulation, salinity problems

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1. Introduction

Water scarcity occurs where there are insufficient water resources to satisfy long-term average requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system.

Although water scarcity often affects areas with low rainfall, human activities add to the problems in particular in areas with high population density, tourist inflow, intensive agriculture and water demanding industries.

Losses of water in the supply network are often substantial in several water-scarce regions in Europe. For example in France and Spain as much as 30% and 24–34%, respectively, of water is lost before it reaches the consumer (http://www.eea.europa.eu/themes/water). On Northern Cyprus (NC) the water loss in the distribution system is about 30–60% (Mavioglu, 2004).

Water scarcity on NC is expected to increase in the future due to increases in population and in per capita water consumption owing to changes in living standards and cultivated areas. In this study, water scarcity problems and alternative strategies to overcome water scarcity problems on Northern Cyprus are discussed.

2. The water scarcity problem

2.1. WATER SCARCITY IN THE WORLD

Water is becoming a more and more important commodity all over the world owing to global changes, including population increase, industrialization and climate change. The continuous increase in water extractions has reduced groundwater stores. The effect of urbanization and evaporation owing to global warming reduced the replenishment of aquifers and surface water resources. In addition, pollution of water reduces total usable water yields.

The State Hydraulic Works of Turkey (DSI) classifies countries as poor, insufficient or rich according to the amount of available water per capita per year (www.dsi.gov.tr).

- **Poor:** Annual water volume per capita is less than 1,000 m^3.
- **Insufficient/water stress:** Annual water volume per capita is less than 2,000 m^3.
- **Rich:** Annual water volume per capita is more than 8,000 m^3.

Although water scarcity is becoming a global problem, it is more severe in some countries as can be seen in Table 1.

TABLE 1. Countries experiencing water scarcity in 1955, 1990 and 2025 (projected), based on availability of less than 1,000 m^3 of renewable water per person per year.

(http://www.itt.com/waterbook/intl.scarcity.asp)

Water-scarce countries in 1955	Countries added to the scarcity category by 1990	Countries added to scarcity category by 2025 according to UN population growth projections	Countries added to scarcity category by 2025 only if they follow UN medium or high projections[a]
Malta	Qatar	Libya	Cyprus
Djibouti	Saudi Arabia	Oman	Zimbabwe
Barbados	United Arab Emirates	Morocco	Tanzania
Singapore	Yemen	Egypt	Peru
Bahrain	Israel	Comoros	
Kuwait	Tunisia	South Africa	
Jordan	Cape Verde	Syria	
	Kenya	Iran	
	Burundi	Ethiopia	
	Algeria	Haiti	
	Rwanda		
	Malawi		
	Somalia		

[a]Cyprus will have more than 1,000 m^3 of renewable fresh water annually per person in 2025 if it follows either the UN low or medium population growth projection. Zimbabwe, Tanzania and Peru will avoid falling below 1,000 m^3/capita only if they follow the UN low projection.

2.2. WATER SCARCITY ON CYPRUS

Cyprus is the third largest island in the Mediterranean Sea after Sicily and Sardinia, with an area of 9,251 km^2. It is situated in the Eastern Mediterranean Basin at the crossroads of the three continents of Europe, Asia, and Africa (Figure 1), and it possesses a coastline of 1,364 km. NC is the northern part of the island with 3,355 km^2 , approximately one third of the whole island. Nearly half of the coastline of the island is also within the boundaries of the TRNC (Elkiran, 2006).

Cyprus, having a typical Mediterranean climate of mild rainy winters with hot summers, has an average annual rainfall of about 500 mm, ranging from 290 mm on the plains to 1,100 mm in the mountains falling through October to April. Class A pan evaporation during the year rises up to 2,000 mm (Tsiourtis, 2002).

The temperature in the North is around 5^{o}C in the mountains in winter and reaches above 40^{o}C in summer on the plains, whereas the average rainfall is 295 mm on the plains and reaches 457 mm in the mountains (Goymen, 2003).

Water scarcity in the country started in 1960s and soon after, several studies identifying the situation were carried out by the United Nations Development Program (UNDP, 1970). Unfortunately, the continuous over extraction of water from underground resources in recent years caused some of the coastal aquifers to be salinated up to 5,000 ppm NaCl and some others even depleted locally in the inner parts of the country (Elkiran and Ergil, 2002).

Unrestricted water extraction, increase in the population, contamination of water resources and salinization of the coastal aquifers reduced the safe yield of water that can be supplied to households (Mollaoglu, 1985).

Figure 1. Geographical location of NC (Turkish Cypriot administered area).

The backbone of the economy of the country is agriculture, where small farms are prevalent. Citrus fruit cultivation produces the majority of the exports of Northern Cyprus. Irrigation plays a great role in the efficient yield of these fruits (Ergil, 1999).

Cyprus has experienced a drought for the last 30 years. As a consequence, water shortages have been a serious problem for the same number of years on NC, which has a population of 200,000 inhabitants living on an area of 3,299 km^2. The problem felt is not only a problem of quantity, but also a problem of quality. In other words, apart from not having sufficient quantity, the quality of the existing water supply is also unsatisfactory. The quality of drinking water in most areas is below world standards. Despite the fact that NC has a total land area of 329,890 ha (3,299 km^2), 187,069 ha (56.70%) is used for agriculture and only 9,482 ha (5.07%) of this is used for irrigation-based agriculture (Gökcekus, 1999).

NC, having water availability of 285 m^3/capita-year, is considered a water-poor country. Since the domestic water consumption is 250 liter/capita/day, the difference is supplied from groundwater resources by over-abstraction, which results in sea water intrusion.

3. Impacts of water scarcity on Northern Cyprus

Impacts of water scarcity on Northern Cyprus can be grouped as follows:

3.1. DOMESTIC WATER QUALITY

In the 1960s, the main aquifer supplying water to the whole country was Magosa aquifer, which is situated in the east of NC. However, over-abstraction from this resource caused complete salinization of the aquifer and now it is out of use (Ozturk, 1995). Soon after; all the pressure was transferred to Guzelyurt aquifer, which is located in the west of the country. Over extraction from this aquifer continued, and the aquifer water quality was reduced to 5,000 ppm in salinity in some local regions. Hence, the tap water cannot be used as a drinking water and bottled water is preferred (Bozer, 1999, Ergil, 1999).

3.2. AGRICULTURAL CULTIVATION PRODUCT QUALITY AND ECONOMIC REVENUE

On NC, agriculture contributes a lot to the economy. Citrus fruit occupies the greatest part of the production in agriculture and the revenue from this export is also high (Elkiran and Ergil, 2004).

The distribution of cultivated area and production yield of citrus fruit for the three main regions on Northern Cyprus are, 5,475 ha for Lefkosa (16 t/ha), 53 ha for Gazimagusa (12 t/ha) and 361 ha for Girne (4.5 t/ha). Approximately, 39.4% of the citrus fruits are exported to other countries, nearly 6% is consumed within the country and 54.6% is used in the industrial sector. Due to limited water resources and degradation of water quality, only 10% of the total agricultural land can be cultivated (ASP, 1996–2004).

On NC, the water consumption within the aquifers is far beyond their safe yields, and the fruit yields of the crops are far below expectations. As an example, the average yield of orange trees was 15 t/h, in 2001, whereas the expectation was 35 t/ha. The decrease in the yield can be seen in all crops and orchards (ASP 1996–2004, Markou and Mavrogenis, 2002). In addition, the decrease in yield is becoming worse every year (ASP, 1996–2004).

Owing to the limitations in water resources and decrease in water quality, agricultural income in 2001 was found to be 41 million US Dollars; however it would be 72 million US Dollars if water quality and land reclamation were considered (Elkiran, 2006).

4. Alternative strategies

To overcome water scarcity problems on Northern Cyprus, the following strategies have been evaluated.

4.1. TRANSPORTING WATER BY TANKER FROM TURKEY TO NORTHERN CYPRUS

In 1998, large water bags towed by tankers of varying capacity from 10,000 to 40,000 m^3 were found feasible, in order to supply municipal water needs. These bags were filled with water in Aydincik, Turkey, and brought to Kumkoy reservoir on Northern Cyprus (4.1 MCM in 5 years) (Bicak and Jenkins, 2000).

The technical problems experienced during transportation made the project inefficient for water transfer. Thus, the contract between the company and the General Directorate of State Hydraulic Works (DSI) was terminated and the project stopped in 2002 (Sidal, 2006).

4.2. TRANSPORTING WATER BY PIPELINE FROM TURKEY TO NORTHERN CYPRUS

An alternative solution to the water scarcity problem was assumed to be transporting water by pipeline from nearby Turkey so as to reduce the deficiency of the available water resources. About 75 million cubic metres of water is aimed to be conveyed from Turkey to Cyprus annually, of which 15 million m^3 of water will be transported to a reservoir that will be constructed near Lefkosa city to provide an additional domestic water supply to the city. This will relieve some of the pressure on the aquifers and the remaining water will be diverted to the Mesaoria plains for agricultural purposes to irrigate 7,650 ha of cultivation land. The pipes, made of high density polyethylene (HDPE), will be submerged 250 m below sea level with a diameter of 1,600 mm. The estimated cost of the project is expected to be about US$300 million. It is obvious that transferring water from Turkey to Northern Cyprus is the probable alternative solution in order to eliminate the deficit of groundwater resources (www.dsi.gov.tr).

4.3. SEAWATER DESALINATION

Seawater desalination has some advantages as indicated below:

- It is a reliable and independent water source.
- Costs are decreasing due to advances in research and development.

Desalination plants have already been implemented on Southern Cyprus in the 1990s and on Northern Cyprus in the first decade of the twenty-first century. The number of desalination plants is increasing (Elkiran, 2006).

The use of desalinated water on NC is very limited. Two institutions located on the coastline have succeeded in producing about 0.4 MCM per year at a cost of 0.7 Euro/m^3 (Elkiran, 2006). However, the moderate scale desalination plant constructed in the Karpaz region in order to serve the new hotels and the stakeholders in the region as a domestic use is based on a Build-Own-Operate-Transfer system, under which the cost is about US$0.95/$m^3$ and the quantity of water treatment is expected to be 2,000 m^3/day (Kibris, 2007).

4.4. IRRIGATION DEVELOPMENT

The modernization of irrigation systems began in 1998 in Northern Cyprus using a subsidy from the government. At present, about 80–90% of the modernization project has been achieved. About 80% of the irrigation system is drip irrigation (ASP, 1996–2004).

4.5. WASTEWATER REUSE

The Lefkoşa Wastewater Treatment Plant treats almost 12,000 m^3 of water every day. Wastewater is taken not only from the North but also from the South. However this water is released to the channel to flow to the sea (Oznel, 2003).

The reuse of effluent water should be studied, and use of this water must be enforced among farmers and some other sectors in the area.

At present, wastewater is only used for irrigating playgrounds treated in small individual systems (Elkiran, 2006).

5. Results and discussion

The water scarcity problem on Northern Cyprus cannot be ignored, especially when future projections of water needs indicate a gap of 32 million cubic metres by 2035. Hence, alternative solutions proposed above should be implemented without any delay (www.dsi.gov.tr).

The first and the best solution from a quantity point of view appears to be transferring water by pipelines from Turkey to NC in order to reduce the pressure on underground resources. However, the expected cost of about US$1/m^3 of water is rather high when compared with the cost of traditional water supplies (Kibris, 2007).

Wastewater reuse in the country must be encouraged for irrigation of gardens for specific crop patterns, like fodder crops and irrigation of home gardens by installing alternative red pipelines separated from the green fresh water lines. The expected water savings is about 33% for home treatment systems (Elkiran, 2006).

Desalination water techniques are developing day by day, allowing the fresh water to be treated more cheaply. NC is surrounded by the sea, hence desalination of sea water seems to be an alternative reliable solution to water scarcity in the country. Since return of brine water from the system to the sea will be easy and economical, desalination systems will have a distinct advantage over other alternatives.

The irrigation water in the country consumes almost 70% of the total water used per year. However, the benefit from this sector is decreasing due to salinization of the fresh water caused by sea water intrusion following excess water withdrawals during the year. In the meantime, the tourism sector is suffering from the unsatisfactory water supply through the system. The water supply can be altered so that the irrigation of less profitable agricultural land might be avoided and some additional water can be supplied to the tourism sector. Furthermore, land reclamation in the country should be encouraged, considering the suitability of water quality and quantity, soil texture, climate and high value crop patterns, in order to reduce the water extraction from existing resources and increase revenues (Elkiran, 2006).

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Landsat ETM+ image of Cyprus from January 30, 2001.

ECONOMIC EVALUATION OF FARMERS' ALTERNATIVES DURING IRRIGATION WATER DEFICIT

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Abstract. This study evaluated the expected impacts that water shortage will have on crop production and farm net income on a typical private farm in Namangan region, Uzbekistan. A Linear Programming (LP) model is used to find the combination of responses that will leave the farmer with the highest possible net income given the levels of water available. If improved irrigation practices are not a realistic alternative, farmers are left with no ways to avoid deficit irrigation when water is short, and cotton production and farm net income both fall almost in proportion to the water deficit. However, if improved irrigation practices are adopted, the model indicates that full production and income can be sustained with about 20% less water in the critical period. The improved methods also give more timely and uniform irrigation that, according to research results, will increase yields and income by more than enough to pay for the extra labor required.

Keywords: Optimization, linear programming, deficit irrigation, irrigation efficiency, cropping pattern

1. Introduction

Irrigation is vital for agriculture in Uzbekistan. More than 80% of farmed land is irrigated and more than 90% of crop production is from irrigated land. Many areas suffer water shortages, especially in late summer; so there is a need to make the best possible use of available water.

Conventional furrow irrigation is the predominant method in Uzbekistan. Substantial water losses occur in the on-farm irrigation system and in the

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field. Irrigation water use per hectare is much higher compared to other regions with similar climatic conditions. For instance, The World Bank reports that farmers in Uzbekistan use on average 14,000 m^3/ha for irrigation of cotton, while Turkey and Egypt use about one third less (The World Bank, 2000). Also, yields of Uzbekistan's main crops (i.e., cotton and wheat) are reported to be less than one-half of what is produced elsewhere.

Meanwhile, poor management and declining technical conditions of irrigation infrastructure are reducing the capacity for water delivery to the farms. Currently, water is provided free by the state's distribution agencies. The introduction of water charges would create incentives to save water and improve the situation with land and water resources and the environment.

This study evaluated the expected impact water shortage will have on crop production and farm net income of a typical private farm in Namangan region, Uzbekistan. A Linear Programming (LP) model is used to find the combination of irrigation practices and cropping pattern that will leave the farmer with the highest possible net income at different levels of water supply.

2. Farm characteristics

2.1. CHARACTERISTICS OF FARMS AND FARMERS

Namangan region was selected as a study area for this research. It is located in the northern part of the Fergana Valley in the far eastern part of Uzbekistan. It includes 265,000 ha of irrigated agricultural land. Irrigation water is supplied from the Syr Darya via systems of channels and pumps and often reaches the fields in open and unlined channels. Namangan region consumes about 3,300 million m^3 of water each year for agricultural use. This region is densely populated and has an abundant supply of labor.

A survey was conducted in the Namangan region in the summer 2005 to obtain information about private farms in the area. The survey was conducted by Partnership for Resource and Environmental Management Analysis (PREMA), an international joint project of Washington State University (WSU), USA and Tashkent Institute of Irrigation and Melioration (TIIM), Uzbekistan. The 25 farms interviewed in the survey had an average of 22 ha in cropland of which 8.4 ha was in wheat. The area of land in cotton and wheat is dictated by government orders, and, on the surveyed farms, the proportions compare to provincial averages. Average yields on the farms' 2004 crop were 26 centner/ha cotton and 35 centner/ha wheat, comparable to the regional average.

The surveyed farms were selected for their superior attention to irrigation; however, all of the selected farms furrow irrigate with traditional technology and none reported using improved irrigation techniques. Some farms that experience water shortage do make an effort to improve efficiency. Also none of these farms had measurement of the amount of water applied to the crops.

For the model farm to be analyzed, we assumed 20 ha of cropland used to grow cotton and wheat. For the base case, it was assumed that the farm is required to grow at least 8 ha of cotton and 6 ha of winter wheat with flexibility to choose between the two on the remaining 6 ha.

Farmers' responses to the survey conducted for this study indicated that July–August (denoted as period 4 in this study) is the most critical period for crop water requirements and also the most likely period for water shortage. Therefore, most of the focus of this study was devoted to water supply and its reduction in this period.

2.2. CROP WATER REQUIREMENTS

Water requirements of cotton and wheat were estimated for each of four stages (initial, crop development, mid-season and late) based on the study of Doorenboos and Kassam (1979) and verified on FAO (2006a and 2006b). Crop water requirements are satisfied by effective rain and water supplied by irrigation. Irrigation requirements for all periods for each crop were calculated by using the CROPWAT program. CROPWAT was developed by the Land and Water Development Division of FAO (FAO I&D. Paper 46, 1992). CROPWAT uses the climate (mean monthly temperature, precipitation, humidity, wind speed, duration of sunshine) and crop data to calculate crop water and irrigation requirements. Climate information for Namangan region, Uzbekistan was obtained from the CLIMWAT climate database.

The yield response to water for each crop was estimated using the relationship between relative yield (Ya/Ym) and relative water consumption (ETa/ETm) established by Doorenboos and Kassam (1979):

$$Y_a / Y_m = 1 - K_y * (1 - ET_a / ET_m) \qquad (1)$$

where Y_a : actual yield (kg/ha)

Y_m : maximum potential yield (kg/ha)

ET_a : actual water consumption (mm or m^3/ha)

ET_m : maximum potential water consumption (mm or m^3/ha)

K_y : the yield response factor

The yield response factor, Ky is the critical determinant of yield response to actual water available to the plant, ETa, relative to ETm, maximum potential water consumption. The Ky coefficient has been estimated by researchers for several crops and for various development phases within the season. Ky varies depending on type and development phase of the plants and shows whether a plant is sensitive to water in the specific period. The crop or period with the highest yield response factor suffers the greatest yield loss from reduced water consumption. Generally, crops are more sensitive to water deficit during emergence, flowering and yield formation than during early and late growth periods. This implies that timing of water supply is as crucial as the total level of supply over the whole growing period. The most sensitive period for cotton is mid-season stage (period 4 in this study) and for wheat is crop development stage (period 1).

When the irrigation water supply is adequate, fields are generally irrigated to achieve ETa = ETm in all periods and reach maximum production Ym. In this practice, called biological optimum irrigation, plants are irrigated whenever needed to raise the soil moisture content to field capacity and prevent moisture stress that would decrease the plant yield. The amount of water required to prevent moisture stress through the season is called Net Irrigation Requirement (NIR).

If irrigation water available is less than NIR for some reason and, therefore, actual water consumption of the plant lower than its optimum water consumption (ETa/ETm < 1), actual yield will be less than the maximum yield. The decrease in yield will vary depending on time, duration and magnitude of the water deficit. In this case, crop planning, irrigation scheduling and water management become important. There are several options. The area planted to crops with high water requirements or high sensitivity to water shortages may be shifted to other crops that can be more adequately irrigated. A more conservative irrigation technology may be used to improve water use efficiency or deficit irrigation may be carried out. In deficit irrigation, the irrigation water amount is decreased to a certain extent, causing a decrease in yield, but making it possible to irrigate more area with the same amount of water and obtain more income per unit of water.

2.3. FARM COST AND RETURN

The amount of inputs for crop production and their prices were obtained from the survey data and cost and returns budgets developed for the Namangan region in summer 2005. The budgets for cotton and wheat were developed based on US Budgeting standard format. The production costs are divided into two categories, with the first applying to variable costs related to operating machinery, hiring labor, and purchasing services and materials and the second, known as fixed costs, associated with machinery ownership and land. Fixed and variable costs sum to total costs.

3. Alternative activities

3.1. COTTON ACTIVITIES

Alternative cotton production activities were specified based on different irrigation techniques as reported from a research study in Kazakhstan by an Asian Development Bank project (Vishpolskiy et al., 2002). The research in Kazakhstan was in a region with climate condition and agriculture similar to the Namangan region in Uzbekistan. The irrigation techniques studied to determine their water efficiency, compare productivity and profitability were:

1. Traditional furrow irrigation – every furrow on the field is irrigated. Field irrigation efficiency is 50–56%.
2. Every other furrow irrigation – can be described as watering only every other furrow to reduce water loss. The field irrigation efficiency is 55–65%.
3. Surge irrigation – water flow starts at a high level, providing fast movement down the furrow. Then water supply is stopped for a while before again resuming. This technique decreases technological loss of irrigation water through infiltration and runoff and reduces the water flow to the drainage system. Farmers irrigate every other furrow by this technique, and irrigation efficiency is from 65% to 70%.
4. Discrete irrigation – the water supply is stopped when it reaches 80% length of the furrow. After a pause of about 1–1.5 hours, irrigation is restarted at a lower rate of flow. The farmer irrigates every other furrow by this technique. The field irrigation efficiency reaches 67–72%.

The alternative irrigation technologies require more labor, estimated based on the study in Kazakhstan to be 46 additional hours per hectare for every other furrow irrigation, 69 additional hours for surge flow, and 109 additional hours per hectare of discrete irrigation. The budgets developed under the PREMA project were modified to account for extra labor requirements, overhead, and total variable costs and different yields and water use of these four irrigation techniques under the conditions of Namangan region. These four budgets showing in Table 1 are denoted as four basic cotton irrigation activities for the model of this paper.

It is also possible to achieve higher efficiency with conventional furrow irrigation by closer monitoring and improving precision in irrigation, improving uniformity within the field, timing irrigation more closely to crop water requirements and soil moisture levels, more frequent irrigation, and dividing fields into shorter lengths of run. But, we had no data on

TABLE 1. Costs and returns for cotton production, four irrigation techniques, 2005.

Items	Unit	Conventional furrow irrigation	Alternative techniques[a]		
			Every other furrow	Surge flow	Discrete flow
Variable cost					
Fertilizers, Chemicals & machinery	UZS/ha	231,265	231,265	231,265	231,265
Labor, including:	UZS/ha	89,046	99,846	102,546	107,926
Labor for irrigation	UZS/ha	*18,720*	*19,440*	*22,140*	*27,600*
Overhead	UZS/ha	16,016	16,556	16,691	16,964
Total variable cost	UZS/ha	336,327	347,667	350,502	356,235
Fixed cost					
Land Tax	UZS/ha	9,059	9,059	9,059	9,059
WUA fee	UZS/ha	9,000	9,000	9,000	9,000
Total fixed cost	UZS/ha	18,059	18,059	18,059	18,059
TOTAL COST	UZS/ha	354,386	365,726	368,561	374,294
Returns					
Yield	Centner/ha	23.2	25.78	25.78	25.78
Gross return	UZS/ha	584,640	649,656	649,656	649,656
Net farm income	UZS/ha	230,254	283,930	281,095	275,362
Labor					
Total irrigation labor use	h/ha	156	202	225	265
Other permanent labor	h/ha	247	256	256	256
Seasonal labor	h/ha	255	280	280	280
Water					
Field Irrigation Efficiency	%	53%	60%	68%	70%
Water use (m^3/ha)	m^3/ha	11,768	10,395	9,173	8,910
Income/water	UZS/m^3	19.6	27.3	30.6	30.9

[a]Alternative techniques irrigate every other furrow

additional requirements of achieving these general improvements to cotton irrigation. So this study considered only improving irrigation efficiency by applying specific furrow irrigation techniques that display labor-water substitution to maintain a higher yield when water supply is decreased.

Other cotton activities were developed based on reduced water supply relative to NIR in period 4 only. Period 4 is the most critical one for cotton. It was assumed that farmers do not take any actions to better irrigate their field under water deficit conditions, a reduction in water supply is reflected in reduced NIR and reduction in the ratio ETa/ETm (water supply) to the crop. The resulting decrease in yield was calculated by a water-yield relationship in formula 1, substituting for ETa/ETm the reduced ratios of 90%, 80%, 70% and 60% of NIR availability.

Costs for these reduced water supply cases are based on the traditional furrow irrigation activity for cotton. Input and labor costs are assumed to be the same as for traditional furrow irrigation because of the assumption that farmers took no actions to improve field irrigation. However, there is a reduction in permanent labor (excluding labor for irrigation) and in seasonal labor, because of the reduction in yield.

3.2. WHEAT ACTIVITIES

Water use, yield, costs and returns for wheat production activities were based on the survey data and cost and return budgets developed for the Namangan region in summer 2005. Wheat activities for variations in water supply are based on a study of the potential for water markets in Idaho (Whittlesey et al., 1986). Alternative ways of irrigating crops in southern Idaho, including winter wheat, were simulated to reflect the tradeoff that can occur when water supplies are reduced. For each level of water consumptive use, the same levels of irrigation efficiency as for cotton were used (53%, 60%, 68% and 70%). Amount of applied water, a yield index and the estimated yield in centners per hectare for alternative levels of efficiency in irrigating this crop were estimated. An estimate of labor use and the total variable costs of production, adjusted to account for costs that are proportionate to yield, were calculated.

In response to a change in the quantity of delivered water, the farmer may change the level of irrigation efficiency, the consumptive use of water for cotton or wheat, or the hectares of crops that are produced. As the irrigation efficiency and water application for these crops is changed, the labor requirements will also change. The optimum response for a farmer to any given level of water supply will depend upon the price of labor, the prevailing irrigation technology, and the value of the crops that are produced. The responses derived in this analysis are based upon the assumed costs of production, yields and crops.

4. Analytical model

4.1. OPTIMIZATION MODEL

A Linear Programming (LP) model is used to find the combination of irrigation practices and cropping pattern that will leave the farmer with the highest possible net income at different levels of water supply. The objective function of the optimization model is net income from cotton and wheat production. Net income of each activity is sales minus variable costs of production. Maximization of net income is constrained by the limited availability of key resources – cropland, irrigation water supply and labor.

Mathematically, the objective function can be written as:

$$\max Z = \sum_{i}^{n} A_{\mathrm{i}}\ GM_{i}$$

Where A_i: planted area of crop i, in hectares

GMi : gross margin for crop i calculated as the difference between market sales and variable costs:

$$GM_{i} = (Y_{i} * P_{i}) - \sum_{j} VC_{\mathrm{ij}} - \sum_{k} (L_{\mathrm{ik}} - LP_{k})$$

Where Yi : the yield from crop i

P_i : price of crop i
VC_{ij} : the variable costs j (such as machinery, fertilizer, seeds and others, but excluding labor) required to produce crop i
L_{ik}: amount of labor k required to produce crop i
LP_k : prices of labor (permanent and seasonal)

QM for Windows software was utilized for solving the linear optimization programming models.

4.2. SCENARIOS

Four scenarios were simulated with the LP model, using different combinations of irrigation techniques, water supply and cropping patterns which are summarized below:

1. Base case
   ventional furrow irrigation (53% efficiency). Farmers are required to grow at least 8 ha but not more than 10 ha of cotton. The area for wheat is required to be at least 6 ha. The amounts of water supplied to the fields are sufficient for 10 ha of cotton and 10 ha of wheat.
2. Reduced Water Supply – Reduction in water supply in period 4 is introduced with the potential for some change in cropping pattern and deficit irrigation but no option for improving irrigation efficiency.
3. Alternative Irrigation Techniques – Introduction of alternative irrigation techniques with higher levels of irrigation efficiency (60%, 68% and 70%) to the Base Case.
4. Reduced Water Supply – Reduction in water supply in period 4 is introduced with the potential of changing to more efficient irrigation techniques as well as changing cropping patterns and deficit irrigation.

5. Results

The LP model was used to determine the profit maximizing (or loss minimizing) cropping program for each of the four scenarios. For Scenarios 2 and 4, the key issue is response to reduced water supply with different combinations of cropping patterns and irrigation technology.

5.1. SCENARIO 1. BASE CASE

Scenario 1 is designed to portray, as closely as possible, the present resource and production situation on a typical farm in the Namangan region. The optimal, net income maximizing, plan for this scenario reflects the economic importance of cotton. As long as irrigation water supply is adequate to fully meet crop water requirements using conventional furrow irrigation, farmers would profit most by growing the maximum permitted 10 ha of cotton. Most of the farmer’s net income comes from the cotton and relatively little from the 10 ha of wheat produced on the rest of their land. Farmers would like to produce even more of the relatively high income cotton crop; however, they generally cannot do so because they do not have enough labor and water in late summer to meet high requirements for even more cotton production and because yields are often adversely affected by too high a percentage of land in cotton.

The combined net return above variable costs from cotton and wheat production is 2,985,000 UZS* (or about US$2,985). Subtracting certain

* UZS – Uzbek Soums (currency in Uzbekistan), USD – US Dollars (currency in USA)

fixed costs (land taxes and WUA fee), leaves about 2,624,000 UZS as net farm income. An additional, 1,057,000 UZS is paid to farm workers, raising the total income received by the farmer and farm worker to 3,681,000 UZS, 184, 000 UZS/ha.

5.2. SCENARIO 2. REDUCED WATER SUPPLY

Scenario 2 is designed to determine the effect on crop pattern and net return when the Base Case farm has to cope with less than a full water supply in period 4. Reduction of water supply in period 4 by only 10% makes it more profitable to slightly decrease the area for cotton and use the land instead for growing wheat. Wheat requires no water in period 4 and thus is unaffected by water supply at that time. Net return declines by 4% and total income to farmer and farm workers declines by 5%.

Further reductions below full water supply can be met in this case only by further decreases in area planted to cotton and, especially after reaching the minimum ordered area in cotton, by deficit irrigation in Period 4. A decrease of 30%, to 70% availability of water in period 4, would lead to a decrease in the growing area of cotton to the minimum permitted 8 ha and increase to 12 ha of wheat. Most of the cotton receives only 90% of NIR and consequently produces a lower yield. Farm net return is down by more then 20%. The marginal value (increased net income that could be gained) from 1 m^3 of water in period 4 at that point would be 40 UZS.

Figure 1 represents changes in net farm income over a range from 100% to 50% of full supply of water available for irrigation in period 4. The reduction in income becomes more pronounced until, at 50% water supply level, farm net income is just 51% of the income with full water supply.

5.3. SCENARIO 3. ALTERNATIVE IRRIGATION TECHNIQUES

Scenario 3 has the same constraints and alternatives as Scenario 1 except for introducing alternative water saving irrigation techniques. With full water supply the profitability of cotton is reflected in the same choice of planting cotton on the maximum feasible area, 10 ha and wheat on the remaining 10 ha Net farm income is, however, 3,244 thousand UZS, 23% higher than net income in the Base Case with 100% of water supply. The reason is that, according to the research study, the improved irrigation methods not only reduce water requirements but also give higher yield primarily because of greater uniformity of application within the field. Thus, it is profitable to adopt the more efficient irrigation methods for their yield-increasing effects, even though the reduced water use is not necessary.

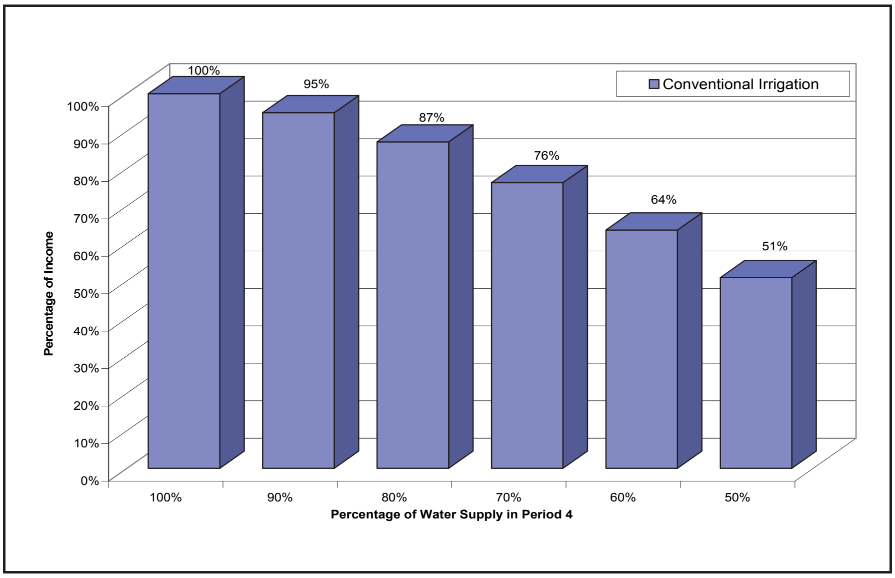

Figure 1. Change in net farm income with decreasing levels of water supply in period 4 – conventional irrigation case.

5.4. SCENARIO 4. ALTERNATIVE TECHNIQUES WITH REDUCED WATER SUPPLY

If the water supply were less than is required to fully irrigate the cotton crop with traditional low-efficiency techniques, it would be profitable to adopt the improved irrigation methods even if farmers did not expect the yield increase that researchers realized. The more efficient techniques make it possible to meet full NIR and achieve maximum yield even though water supply to the farm is reduced. The model results show that it is profitable to make the change even at only a 10% lower water supply. With more severe reductions in water supply, the net income gains from adopting improved irrigation techniques become even larger. The added cost is mostly for additional irrigation labor, and it is more than offset by the drop in income that can be avoided as improved irrigation efficiency makes it possible to avoid yield declines due to failing to meet the crop's full NIR.

Table 2 shows a detailed comparison of optimum values and net income for the scenarios with conventional irrigation only versus scenarios with the option of using alternative irrigation techniques. At 100% water supply in period 4, there are substantial income gains from adopting the improved irrigation techniques even though there is adequate water for full irrigation with conventional low-efficiency practices (Figure 2). Crop production and gross returns are projected to be almost 10% higher. Net farm income is 23% higher, and both labor used and wages earned are up significantly.

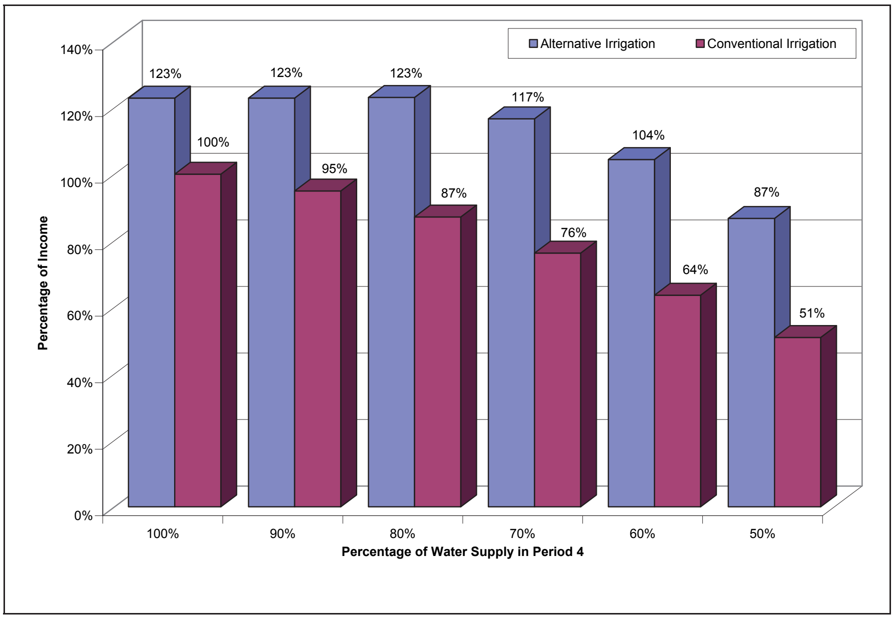

Figure 2. Comparison of change in net income with decreasing levels of water supply in period 4 – conventional only and alternative irrigation techniques cases.

Production and income gains are due to the greater precision of the alternative techniques; however, the higher levels of efficiency make it also possible to produce the maximum 10 ha of cotton while consuming less water (32,000 m^3 less). There would be considerable incentive for farmers to try to use the saved water to increase the area planted to cotton.

The marginal value of the upper bound of cotton acreages was raised by 45,000 UZS above the value when only conventional irrigation is considered. Farmers would profit by planting even more than the government order requires because cotton is much more profitable than wheat.

There are several advantages, beyond simply saving water, for the alternative and more water-efficient technologies.

1. Better yield, 11% higher for cotton according to ADB research report on irrigation techniques used in this study. Greater precision in water application not only saves water but also improves uniformity and reduces over- and under-irrigation of parts of the field. Other reports also attest to potential for greater yield from use of the water conserving technology.
2. More "productive" work for unemployed rural farm workers – total labor use increases by 14% for optimal with alternative versus conventional only irrigation techniques when full water supply is available. The base case requires 7,958 labor hours and the improved

efficiency case increases to 9,048 labor hours. With only 50% of period 4 water, the employment gain with alternative irrigation is 27%. The increase involves more work in irrigation and in harvesting the higher yield.

TABLE 2. Comparison of optimum values and net income with 100% and 50% of water supply in period 4 – conventional only and alternative irrigation techniques cases.

		100% Water supply in period 4			**50% Water supply in period 4**		
	Unit	**Base case**	**Alt. irr.**	**Difference**	**Base case**	**Alt. irr.**	**Difference**
Gross return:							
Cotton	1,000 UZS	5,846	6,497	650	3,689	4,727	1,038
Wheat	1,000 UZS	3,216	3,335	119	3,859	4,002	143
Labor:							
Total irrigation labor use	Hrs	2,360	3,100	740	2,208	3,319	1,111
Other permanent abor	Hrs	3,048	3,143	95	2,637	2,730	93
Seasonal labor	hrs	2,550	2,805	255	1,582	2,040	458
Net return & wages:							
Net farm income	1,000 UZS	2,624	3,244	620	1,336	2, 275	939
Labor wages paid	1,000 UZS	1,057	1,198	141	834	1,052	217
Total income to farmer & labor	1,000 UZS	3,681	4,442	761	2,171	3,327	1,156
Water use & marginal values							
Total water use	1,000 m^3	205	173	-32	168	137	-31
Net return/water used total	UZS/ m^3	13	19	6	8	17	9
Net return/water used in period 4	UZS/ m^3	34	42	8	33	57	24
Marginal water value in period 4	UZS/ m^3	0	0	0	42	61	20

3. Higher incomes:
   (a) Gross income – is increased 770,000 UZS or 8% from the base case, due to the higher yields.
   (b) Net farm income – 620,000 UZS indicating 24% increase from the base case. Many costs are the same per hectare; thus net income increases much more proportionally than does gross income. (But we may have underestimated some increases in non-labor costs such as more fertilizer to support higher yields or more machinery costs for leveling and field preparation).
   (c) Increased total earning of farmer and local workers – 761,000 UZS higher for alternative techniques, a 21% increase.
4. Higher return per m^3 of water – 13 versus 19 UZS/m^3.
5. Much less decline in income form serious drop in water supply in the most critical period (period 4).

6. Conclusion and recommendations

The results of the model show that adopting irrigation methods that improve field irrigation efficiency would allow farmers to not only minimize the effect of water shortage but also to achieve higher yield and consequently higher net farm returns for both of these crops. Water use efficiency can be increased by applying alternative furrow irrigation techniques or by more intensive management using conventional techniques. Either method generally requires more labor for more precise and careful management of water, especially during short periods.

Improved irrigation produces higher income, especially when the water supply is short, but also even with adequate water supply. If improved irrigation practices are not a realistic alternative, farmers are left with no way to avoid deficit irrigation when water is short, and cotton production and farm net income both fall almost in proportion to the water deficit. However, if improved irrigation practices can be considered, the model indicates that full production and income can be sustained even with up to 20% less water in the critical period. Even with a severe 50% shortfall in water supply, net income with improved irrigation techniques is expected to be only about 10% less than income earned with conventional low efficiency irrigation and full water supply.

This study also shows a high shadow price for water when there is a water shortage in the critical late summer period. Farmers could increase incomes even while paying much more than current fees for a greater supply of water in the critical time.

The water management agency should encourage farmers to adopt higher efficiency irrigation technology. Extension services may be used to explain irrigation techniques and demonstrate potential gains to farmers. Monetary incentives could be given for adopting water-saving practices, and pricing excess water use at market levels could promote adoption of more efficient irrigation technology.

Future research should examine the practical technical and economic feasibility of more advanced irrigation technologies; up-front capital investments such as lining distribution canals and ditches, introduction of drip and gated pipe systems, and introduction of forage and livestock production into farm plans.

Research is needed on the relative profitability and water use efficiency of cotton, wheat, other field crops, and vegetable and fruit production on the *dekhqan* plots. More improved and widespread collection of data on farms' costs and returns for different enterprises and types of farms would also be helpful. Also, there is a need for collecting more information on costs and yield effects of alternative irrigation techniques and practices.

Developing more aggregated farm and regional models would be very helpful for evaluating policy alternatives and for developing educational programs for encouraging any adoption of improved irrigation techniques. Aggregated models could be used to study not only allocation of water between crops and technologies on a typical farm but also for finding optimal allocation among different types of farms and different areas.

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AN EVALUATION OF IRRIGATION WATER RE-USE IN WATER DRAINAGE AND COLLECTION NETWORKS IN KARAKALPAKSTAN, UZBEKISTAN

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Abstract. Availability of water is a pre-condition for sustainable land use in any given area. Reclaiming water from irrigation is an alternative option that must be examined in order to meet water demands under conditions of increasing water deficits in the Aral Sea basin. In the territory of Karakalpakstan, Uzbekistan, water flowing in the irrigation drainage network is mostly diverted beyond the boundaries of irrigated lands. As a result, a significant volume of water in the region is wasted due to a lack of return/ re-use in the irrigation process. Additionally, in places where irrigation drainage waters accumulate with different levels of mineralization, the lands are degraded ecologically. Some Central Asian and Near Eastern countries have had positive experiences with return water re-use, including water with low levels of mineralization, for growing different agricultural crops and for supplying water for pastures. Some scientists from Uzbekistan also have conducted fragment-based pilot research to identify the relationships between the mineralization levels of irrigation drainage water for irrigation and yields. The research was experimental in character. It was conducted by selecting the optimal level of mineralization. However, the mechanisms that explain this relationship in terms of the quality of irrigation drainage water are yet to be studied. Researching the interrelationships between water quality structure and soil conditions, physical-chemical processes, the transformations of main pollutants (within soil-waters and plant systems) that occur in the processes of irrigation that use run-off water, will enable determination of the optimal ratio of irrigation water and run-off water mix in order to achieve not only sustainable crop yield but also improve soil conditions and quality of produced crops.

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1. Introduction

A major problem of production in contemporary agriculture is the creation of regional bases of food safety as a factor of stability of the socio-economic situation. In the many flat lands of the Aral Sea basin in Uzbekistan and in the neighboring countries of Central Asia, agricultural production is mainly based on irrigation. Further developing the productivity and sustainability of irrigation-based agriculture is thus a matter of high priority. This matter is especially critical in the context of Uzbekistan, where about 60% of the population lives in rural areas and where agriculture is the main source of income for that majority segment of the country's population.

During the second half of the twentieth century, demographic trends and disproportionate patterns of extensive use water and land resource usage were characterized by:

- Significant rates of a population growth (Uzbekistan's average population growth is 0.8%, and it is 1% for rural population)
- Increasing deficits and deteriorating water quality of rivers
- Trends of environmental degradation and the deterioration of ameliorative conditions of soils throughout the region
- Decreasing yields of adopted agricultural crop varieties and
- Change of socio-economic situations under conditions of new land ownership and land use forms

Water supplies and their conditions in the territory are limiting factors for both sustainable agricultural development and food safety. The flat part of Uzbekistan, where irrigated agriculture has experienced steady deficiencies for about 40 years, is mostly affected by consequences of water scarcity in the basin. Because of river water shortage in most parts of the "hungry steppe", including Dzhizak, Karshi and Sherabad steppes and the Lower Amu Darya region, the optimum irrigation regimes for cultivated agricultural crops are not provided. As the long-term practice of irrigated agriculture shows that despite timely and perfect performance of crop seeding, fertilizing, and all other processes of agricultural production technology, a 10% shortfall of a crop's biological water requirement causes a loss in yield of about 30%. The leaching or leaching regime of irrigation in salinized lands, which is the main agromeliorative method of soil salt regime optimization, is not conducted or conducted within limited land with insufficient amount of water. Losses in potential crop yield on the lands salinized to various degrees range from a minimum of 20–30% up to a maximum of 60–70%.

Optimum use and water resources management within the limits of separate zones or regions requires a differential approach in estimating their volumes and qualitative parameters, conditions of formation, and development of organizational-technological methods ensuring an economically acceptable degree of their use. In this regard, we think that it is obviously necessary to improve planning and use of available water resources within these regions.

2. Mitigating the effects of water shortages

Given the present socio-economic conditions of the countries of Central Asia, which face difficulties of this transition period in their national economies in general and in their agricultural sectors in particular, it is critical that these states develop more efficient and sustainable measures for water use and re-use that conform to the limited nature the water resources of the region.

Under existing circumstances, one of the most realistic alternatives for dealing effectively with water deficiencies in the region involves reclaiming the excess waters that collect in the contours of existing irrigated fields. On the one hand, they otherwise pollute reservoirs and water bodies, and on the other hand, they should be considered as potential secondary resources, which are suitable for re-use in many sectors of each nation's economy (i.e., in both agriculture and industry). In the world today, this practice of re-using waters with high levels of mineralization (i.e., salt content) has a precedence of long-term positive experiences both in industry (as in both Japan and the US) and in agriculture (as in the countries of Southeast and Central Asia, and in the US) (Tanji et al., 1977; Jeannette Warnert, 1998).

In 1999, in those portions of the basins of both the Syr Darya and the Amu Darya that lie within the territory of Uzbekistan, the volume of run-off water accordingly constituted 11.7 mln. m^3 and 14.3 mln. m^3, or 26 mln. m^3 in total. Only 2.4% of accumulated run-off waters from irrigated agriculture are employed as potential resources for re-use (Table 1).

The irrigation drainage water resources formed within the basins of both rivers for 2002 and for 2004 totaled 21,153 mln. m^3 and 23,478 mln. m^3, respectively.

At the same time, irrigation drainage water resources can be re-claimed and utilized only after an assessment is made of their suitability for irrigation.

TABLE 1. Dynamics of a run-off drain for the Republic of Uzbekistan for the period of 1989–1999. (Georgiadi and Milyukova, 2007)

River basins	Year	Total amount 1,000 m^3	Including			
			Discharged to rivers, canals, water reservoirs, 1,000 m^3	Discharged to depressions, 1,000 m^3	Used in their formation	
					1,000 m^3	%
Syr Darya	1989	11,002	8,967	1,482	553	5.5
Amu Darya		9,959	3,665	5,632	662	6.6
Uzbekistan		20,961	12,632	7,114	1,215	5.8
Syr Darya	1991	14,026	11,600	1,846	580	4.1
Amu Darya		10,414	4,149	7,635	660	6.3
Uzbekistan		24,440	15,749	9,481	1,240	5.1
Syr Darya	1993	14,459	12,150	1,858	451	3.1
Amu Darya		14,751	3,974	10,493	284	1.9
Uzbekistan		29,210	16,124	12,351	735	2.5
Syr Darya	1995	11,435	9,271	1,693	471	4.1
Amu Darya		11,179	3,901	6,996	282	2.5
Uzbekistan		22,614	13,172	8,689	753	3.3
Syr Darya	1997	11,711	8,687	2,537	487	4.1
Amu Darya		11,617	4,509	6,866	242	2.1
Uzbekistan		23,328	13,196	9,403	729	3.1
Syr Darya	1999	11,677	9,224	2,014	439	3.7
Amu Darya		13,282	5,254	8,826	202	1.4
Uzbekistan		25,959	14,478	10,840	641	2.5

The results of long-term regular monitoring based on data from fixed check points located in the lower Amu Darya and the “hungry steppe” regions demonstrate that an average annual mineralization of return water from main and inter-farm collectors in most cases varies from 1.8–2.5 up to 4–5 g/L, according to fife score assessment scale of the irrigation that combines parameters of sodium adsorption ratio (SAR) and the sums of salts categorized as “satisfactory” (Rabochev, 1984).

A special attempt to estimate the degree of suitability of irrigation drainage water on a test site of several main collectors serving the territory of northern Karakalpakstan using standard criteria was conducted as part of a study supported within the framework of the IFAR 2007 Grant Fellowship Program. Research demonstrated that the above-mentioned irrigation drainage water could be regarded as an additional source of irrigation water for crops in the period of July–September (i.e., during the period when mass irrigation occurs) (Table 2).

TABLE 2. Parameters of the degree of suitability of irrigation drainage water of Karakalpakstan for irrigation (collector KKS).

Mos.	Average mineralization (g/L)	Parameters of degree of suitability				Monthly average flow (m^3/s)	Annual (m^3)
		PS	SAR	Mg	Cl/SO_4		
2003							
July	2.1	44.62	8.5	42.57	3	1.7	4553280
Aug.	1.83	45.72	9.8	49.71	3	4.1	10981440
Sept.	1.9	51.6	10.7	40.62	3	3.5	907200
							15534720
2004							
July	1.932	40.23	4	55.27	5	1.4	9072000
Aug.	2.106	41.93	6.8	50.77	3	3.6	9642240
Sept.	2.677	46.83	8.7	46.14	3	2.2	5702400
							24416640
2005							
July	2.009	37.05	7.5	59.1	3	0.9	2410560
Aug.	2.152	37.28	5.3	58.73	5	1.2	3214080
Sept.	2.236	31.84	4.5	56.85	3	3	7776000
							13400640
2006							
July	2.209	36.52	5.8	42.52	3	21.7	58121280
Aug.	2.259	36.53	5.5	52.83	3	22.8	61067520
Sept.	2.408	42.68	6.7	51.37	3	20.9	54172800
							173361600

There is also a common precedence in international experiences of collector drainage water resource re-use in the irrigation of different crops. Such cases were particularly common for irrigation of cotton and rice (B.A. Zayed, W.H. Abou El Hassan), Siria (Syria, Salman, M.; Syria, 1999) and of eucalyptus trees in the Tulare Lake basin (Oster et al., 1999). The research data demonstrates not only the feasibility of collector drainage water resource re-use for irrigation but also some improvement in soil ameliorative condition and decreased land under salinized lakes (Bermuda grass in San Joaquin Valley (Dennis Corwin (2005)).

Nevertheless, it needs to be pointed out that an important aspect of collector drainage water resource re-use for irrigation is the protection of product quality.

It is accepted that the basic parameter of profitability for cotton production is the amount of fiber with the appropriate technological parameters determining its commodity cost. According to literature, in cases where the degree of salinization of irrigation water and soil aeration zone increase, there is a corresponding increase in the metric number, model, staple and general length of cotton fibers, and their uniformity is reduced.

These consequences have essential distinctions in cases of different soil-climatic zones and, apparently, are caused by the type of soil salinization, irrigation drainage water, and features of different varieties of cotton. However, to a greater degree they are caused by separation of the methodical approaches and structure of research objectives in the statement of experimental studies on re-use of irrigation drainage water for irrigation of agricultural crops.

TABLE 3. Parameters of the degree of suitability of irrigation drainage water of Karakalpakstan for irrigation (collector KS-4).

Mos.	Average mineralization (g/L)	Parameters of degree of suitability				Monthly average flow (m^3/s)	Annual (m^3)
		PS	SAR	Mg	Cl/SO_4		
2003							
July	1.464	40.38	8.4	49.71	3	4.9	
Aug.	1.409	45.82	6.2	54.51	3	1	
Sept.	1.416	37.13	6.3	43.47	3		
							15802560
2004							
July	2.509	47.67	8.5	47.98	3		
Aug.	1.476	28.35	3.3	51.98	3	1.8	4821120
Sept.	1.44	40.98	5	57.61	3	2.9	7516800
							12337920
2005							
July	2.535	38.52	7.3	45.55	3	0.6	1607040
Aug.	0.881	28.5	2.4	40.5	2	2.3	6160320
Sept.	1.209	3.5		43.8	2	4	10368000
							18135360
2006							
July	1.752	33.12	4.3	30.24	3	3.8	10177920
Aug.	1.758	43.86	6.3	52.9	3	1.9	5088960
Sept.	1.995	37.31	5.5	38.5	3	2.8	7257600
							24606720

TABLE 4. Review of data on impact of irrigation drainage water re-use for irrigation.

#	Place and date(s) of experiments	Soils	Authors	Mineralization of water used for irrigation (g/L)	Cotton yield (100 kg/ha)
1	Hungry steppe 1971–1979	Serozemno-lugovie, Loamy soils low degree of salinization	Bespalov N.F., 1984	River water 2.7 3.5–4.3	32.7 29.6 26.7
2	Hungry steppe 1977	Serozemno-lugovie, Loamy soils low degree of salinization	Glukhova T.P., Koroleva G.A., 1997	River water 2.3 3.1	40.8 33.4 24.3
3	Hungry steppe 1978–1980	Light loamy soils with low degree of salinization	Ramazanov A.R., 1991	River water 3.0 5.0 7.0	30.0 23.1 20.3 19.4
4	Karshi steppe 1974–1979	Takir heavy middle loamy soils with low degree of salinization	Bobokulov Kh. Mallaboev N., 1984	River water 2.0 4.0	41.8 39.7 39.6
5	Ferghana valley 1960–1963	Serozemno-lugovie, Loamy soils low degree of salinization	Ibragimov G.A.	River water 4.8	32.4 28.3
6	Ferghana valley 1974–1980	Lugovo-serazemnie loamy soils with low degree of salinization	Bespalov N.F.	River water 2.5 4.0	36.2 35.5 34.3
7	Lower Amu Darya 1979–1981	Lugovo-alluvialnie, loamy soils with low and middle degree of salinization	Ramazanov A.R.	River water 2.5–4.0 4.4–6.2	33.1 28.2 23.4

3. Conclusion

During recent years, we have observed the gradual transition of many branches of the national economy, including shifts in agriculture under changing market conditions. The re-organization into private farms is finished, an activity that was undertaken basically to re-structure production of agricultural commodities to meet the needs of internal and external markets. Increasing the profitability from producing agricultural commodities including cotton fiber, grain, and others served as the basic criterion in this re-organization. Therefore when selecting the criteria (type, mineralization) and justifying the technology of irrigation drainage water re-use as an additional alternative source for irrigation (terms, amount, sequence, the duration), it is necessary to proceed from necessity of minimization or maximal avoidance of negative consequences to the quality of the product (fiber) and environmental conditions of territory. In this regard, it is obvious that employing an interdisciplinary approach is essential. Studying chemical and physiological processes for a system of "soil – collector-drainage water – plant," should allow the establishment of optimum quantitative parameters for these processes, under which profitable agriculture can be developed and sustained.

Despite this, when collector drainage water resources are re-used for irrigation all technological requirements of crop irrigation with such water should be carefully met. Special capacity-building measures, first of all related with training of farmers should be conducted.

Thus it can be concluded that collector drainage water resources are a real way of combating water scarcity problems in typical regions. However, the following measures should be considered and/or undertaken as preliminary measures prior to implementing a system for collector drainage water resource re-use in irrigation:

- Careful consideration and selection of crop variety
- Studies of both the agro-technical methods and the environmental impacts of collector drainage water resource re-use in irrigation in terms of different soil and amelioration conditions in potential regions
- Development of recommendations for collector drainage water re-use for irrigation for specific conditions and
- Capacity-building and the training of farmers and other water users who re-use collector drainage waters in irrigation

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THE ROLE OF THE AMU DARYA DAMS AND RESERVOIRS IN FUTURE WATER SUPPLY IN THE AMU DARYA BASIN

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Abstract. Central Asia still remains as an area of substantial water stress problems caused by climate change, over-consumption of water resources and soil salinization. The rapid recession of glaciers along with a concurrent increasing frequency and intensity of extreme droughts has led to a progressive reduction of the already scarce resources. As in many other arid and semi-arid zones, surface waters in Central Asia are heavily regulated by extended river-reservoir systems, which affect both the quantity and the quality of water. The large dams and reservoirs of the Amu Darya basin should not only be a matter of international dispute, but also considered as an option to adapt to climate and global change and to the future water shortage in the region. With the Nurek and Rogun dams in the upstream part of the Amu Darya basin and the downstream dam system, the Tuyamuyun Hydroengineering Complex (THC), the region already has a high potential for improving the future water supply by adapting the management of the dams according to site specifications. The main scope of this study is to introduce this potential as an applicable instrument for implementing a sustainable water management strategy in the Amu Darya

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basin. Although this potential or the opportunities dams provide is not always obvious, the results herein received make clear that the management of large dams and reservoirs is an effective measure to improve the resulting water quality and to contribute towards a safe water supply through a modified use of already existing infrastructure.

Keywords: Amu Darya basin, role of dams and reservoirs, water supply, enhanced reservoir operation, water quality, water quantity

1. Introduction

After the break-up of the Soviet Union attention was first focused on water sharing agreements and only later did attention shift to large dams as water control infrastructure in Central Asia (Wegerich et al., 2007). Smith (1995), looking at water sharing arrangements, argues that "nowhere in the world is the potential for conflict over the resources as strong as in Central Asia."

Since the end of the Soviet Union, there has been an ongoing debate on the impact of large dams on water availability and allocation within the Amu Darya basin. Nevertheless, until today both the regional and also the international discussion are quite affected by speculation, assumptions and only sparsely available reliable information.

Before the independence of the Central Asian republics, the predominant water use was for irrigation along the middle and downstream water sources of the Aral Sea tributaries. The area under irrigation increased dramatically from 1960 to 1994 when, based on the 1995 TACIS report, the total irrigated area in the Aral basin reached a maximum of 7,400,000 ha (Tanton and Heaven, 1999). The political and economic independence of the Central Asian republics resulted in a number of changes. While the downstream republics Uzbekistan and Turkmenistan sought to maintain their intensive irrigation, the upstream republics Tajikistan and Kyrgyzstan, having few other options for improving energy supply, built new dams and modified the operation of existing dams to increase hydropower generation.

Glacial and snow melt is essential for the well being of all of the states of Central Asia and provides over 90% of their water requirements. Climate change is causing rapid recession of the glaciers, which helps to meet the states' ambitious water requirements in the short term, but in the long term decreased runoff and increased evapotranspiration from higher temperatures will result. Additionally, climate change has an effect on the frequency and intensity of extreme droughts, with the consequence of increased exceptional water deficits as occurred in the lower Amu Darya during 2000–2002.

Especially because of drought conditions, over-consumption of water resources and soil salinization in Central Asia remain key factors for water stress problems. As a result of the overall reduction in water quantity, the availability of drinking water with tolerable salinity levels is limited (Kayumov and Ikramova, 1997) and water security is seriously endangered.

As in many other arid and semi-arid zones, surface waters in Central Asia are heavily regulated by extended river-reservoir systems, affecting both the quantity and the quality of water. Management of large dams and reservoirs is an effective measure to improve the resulting water quality and to contribute to a safe water supply through a modified use of already existing infrastructure. Therefore the main scope of this study is to introduce the potential of the large dams and reservoirs as an applicable instrument for implementing a sustainable water management strategy in the Amu Darya basin.

Until now a number of issues have been also published in various individual publications and at conferences in Central Asia and in Europe. To enable a more comprehensive picture this paper also aims to combine the introduction of new insights with a compilation of previous materials. We hope that this synthesis will provide young scientists and established experts with a new interest in Central Asia with a first insight into the topic presented.

2. Hydrography of the Amu Darya basin

The Amu Darya is, with a total mean discharge of 79.3 km^3/a, the largest river in Central Asia. It is formed by the confluence of its main headwater tributaries, the Vakhsh and Pyanj Rivers. The total length of the Amu Darya from the head of the Pyanj River to the Aral Sea is about 2,540 km, whereas the length from the river confluence amounts to 1,415 km. (Froebrich and Kayumov, 2004). The catchment area (Figure 1) of the Amu Darya basin comprises 309,000 km^2 and is shared by Afghanistan and four Central Asian Republics: Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. The annual flow regime of the Amu Darya is regulated upstream and downstream by large dams. In the upstream area these are the Nurek and Rogun dams, and the downstream area is characterized by the influence of the Tuyamuyun Hydroengineering Complex (THC).

The Amu Darya tributary Vakhsh River originates in the alpine regions of the Pamir Alai in the southeast territory of Kyrgyzstan, where parts of the Abramov glacier and the Fedchenko glacier contribute to run-off generation. The river flows from north-central Kyrgyzstan to the south-west of Tajikistan.

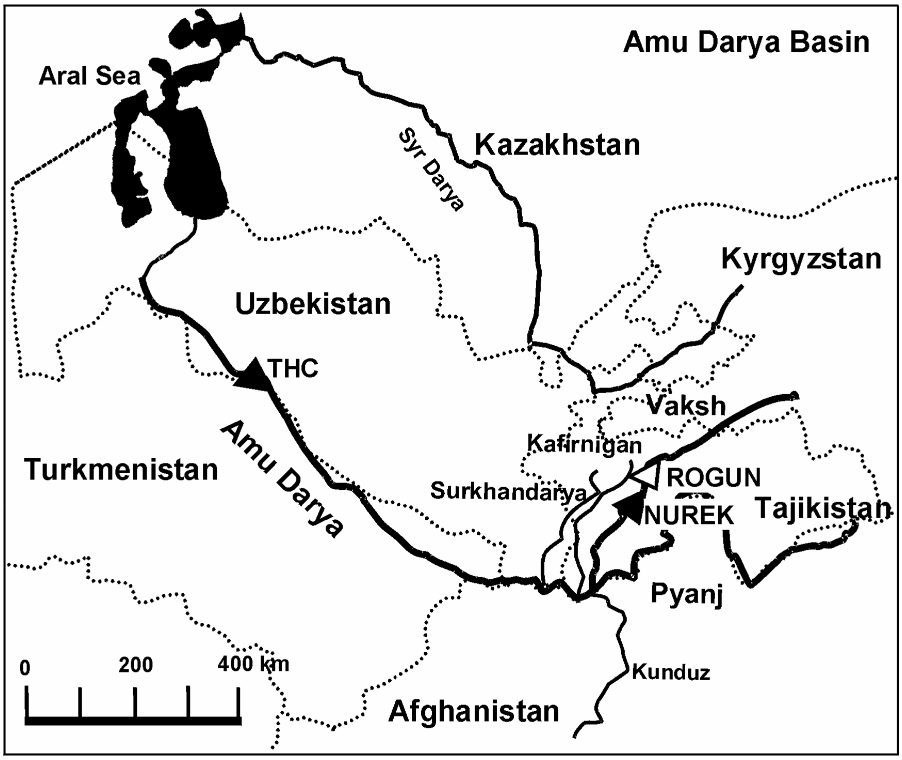

Figure 1. The Amu Darya basin with its main tributaries and the dams of Rogun, Nurek and Tuyamuyun Hydro Complex (THC).

Until its confluence with the Pyanj, the Vakhsh has a length of 524 km, and a catchment area in Tajikistan of 31.2 thousand km^2. The largest tributaries of the Vakhsh are the Miksu and the Obihingou (UN, 2004).

The average annual runoff of the Vakhsh River at the site of the Nurek dam is equal to 20 km^3; there is a 10% probability of a 23 km^3 runoff, and a 90% probability that runoff will not exceed 16.6 km^3. Giese et al. (2004) report an annual mean discharge of 20.0 km^3/a for the Vakhsh and a mean discharge of 34.3 km^3/a for the Pyanj. The Vakhsh contributes only 25% to the total mean discharge of the Amu Darya (79.3 km^3/a).

The Pyanj originates at the glacier in the Vakjdjir Pass, and forms the border between Afghanistan and Tajikistan. The tributaries of the Pyanj are located in Afghanistan and Tajikistan. The major tributaries from Afghanistan are the Wakhan, Pamir, Badkhshan and Kokcha. The major tributaries from Tajikistan on the Pyanj are Gunt, Bartang, Vanch and Kyzylsu. After the confluence of the Vakhsh and Pyanj, the Amu Darya receives water from the Kunduz (from Afghanistan), the Kafirnigan (from Tajikistan), and the Sherabad and Surkhandarya (from Uzbekistan) rivers. The Afghan rivers

Khulm, Balkh, Sar-e-Pul and Sherintang are mostly consumed locally and reach the Amu Darya only rarely (Ahmad and Wasiq, 2004).

The hydrologic regime of the Amu Darya can be described by an uneven temporal distribution of the annual runoff volume, with about 80% within the period April to September. The greatest amount arises in mid summer due to the snow- and glacier melting in the Pamir-Alai Mountains. During the period from 1957 to 1980 the glaciers of the region have lost 126 km³ of ice (around 113 km³ of water) caused by climate change. The amount accounts for 19% of the total ice reserves in 1957 (National Commission of the Republic of Uzbekistan on Climate Change, 1999).

The typical flow regime by monthly averaged discharges of the lower Amu Darya at the site of the Tuyamuyun Hydro Complex (THC) is presented in Figure 2 for the reference station Darganata (1981–2006).

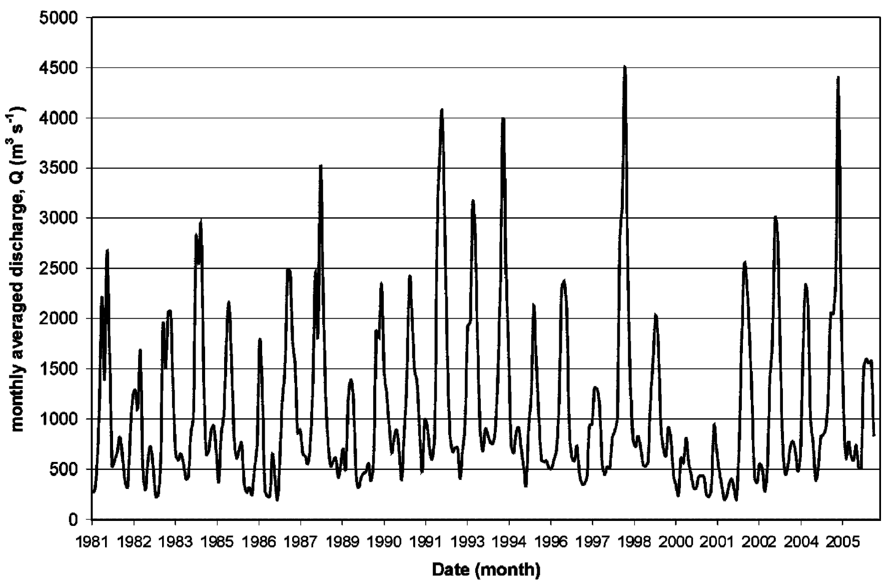

Figure 2. Monthly averaged discharge for the lower Amu Darya recorded at the Darganata station, 1981–2006.

Here, the rise in river run-off begins in April/May and the flow maximum is reached in July of each year. It indicates highest discharges in summer and the lowest in winter, independent from the general water availability. Since ancient times this specific flow regime with its flood maximum in the summer has supported irrigation by providing water at the needed time.

2.1. UPSTREAM DAMS

2.1.1. *Nurek dam – hydropower for Tajikistan*

The hydraulic potential of the Vakhsh River is mainly used for energy generation but to a small extent also for irrigation purposes. Over 95% of electricity in Tajikistan is generated by hydrolelectricity power plants, particularly Nurek HEP (10.5 TWh/a) (Schmidt et al., 2006). Originally the Nurek dam was designed and used to increase the water supply during the irrigation season. Today the reservoir is also used to release water for hydropower production during the winter months (Wegerich et al., 2007).

The Vakhsh is dominated by the Nurek reservoir, which is located about 75 km east of Dushanbe. The Nurek is a large earthfill dam 300 m high. Its reservoir, with a design capacity of 10.5 km³, is the largest reservoir in Tajikistan. It is over 70 km long, with a surface area of over 98 km² and a maximum depth of 220 m (Sherman and Rafikov, 1992). The reservoir bottom has a design level of around 680/690 m above sea level (a.s.l.), and the normal pool level (NPL) elevation is 910 m (a.s.l.). The operation of the Nurek reservoir is characterized by water level variations between the maximum operating level of 910 m (a.s.l) and minimum operating level of 857 m (a.s.l.). Within this range, the active regulation storage of the conservation pool is 4.5 km³, providing seasonal stream flow regulation of the Vakhsh River (Sherman and Rafikov, 1992), while in total the inactive/dead storage between the water levels of 680 m and 857 m (a.s.l.) amounts to 4.0 km³, according to the design capacity.

Nurek's current mode of operation demonstrates its dual role of water control to support downstream irrigated agriculture and to produce energy. Figure 3 shows daily values for water levels, inflow and outflow in 2003 and 2004. The minimum inflow, 57 m³/s in 2003 and 64 m³/s in 2004, occurs during February, with a rapid increase of inflow beginning in March. There is a characteristic sequence of flood events leading to a continuous increase of the average flow. The water level variation is characterized by a continuous decrease during the winter and spring months until the minimum level is reached in May (17 May 2003: 858 m; 6 May 2004: 856 m). Directly after reaching the minimum level, refilling of the reservoir commences and the maximum water level of 910.5 m is reached in autumn (19 August 2003 and 11 September 2004). Subsequently, there is a continuous decrease until May of the following year. This indicates that the Nurek dam is currently utilized to regulate the flow of the Vakhsh River for irrigated agriculture in downstream Turkmenistan and Uzbekistan (Figure 3).

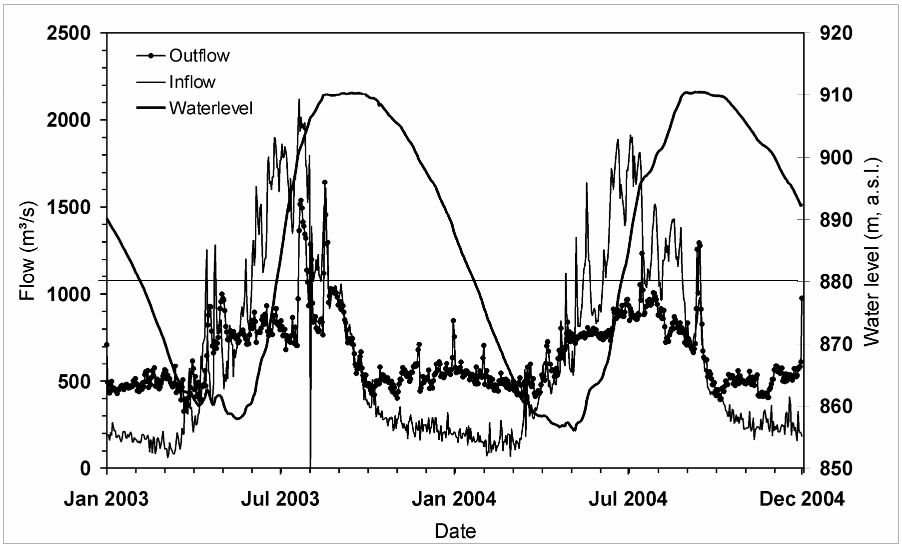

Figure 3. Daily water level variations, inflow and outflow for Nurek reservoir for 2003 and 2004 (Ministry of Energy, Tajikistan, 2004).

A recent World Bank report (2005) states that, during the last 25 years, roughly 50 m of the 300 m have been lost due to silt and that Nurek will be able to operate even without silt removal for at least another 30 years. An earlier World Bank report (2003) had argued that "the Nurek reservoir's capacity has been reduced by 67% over the past 26 years". A more recent survey of the reservoir bathymetry shows that the storage capacity has been reduced from 10.5 km^3 to 8.7 km^3 (17.1%). Therefore, it is questionable whether the World Bank estimate of the lifespan of the reservoir can be accepted unreservedly. In any case, Nurek will slowly lose its capacity to store the water from the summer floods, and also its importance for seasonal water utilization in the downstream regions.

2.1.2. *Rogun dam – increasing the hydropower output*

To increase its energy output, Tajikistan is planning to recommence the construction of the Rogun reservoir (3,600 MW), 100 km northeast of the Tajik capital – a project that was started during the Soviet period but stopped with the Tajik civil war in 1991. The Uzbek government is highly critical of the Rogun dam (Spoor and Krutov, 2003), because it would "put it [Tajikistan] firmly in control of the river" (ICG, 2002). However, neither Spoor and Krutov (2003) nor the ICG (2002) report distinguish between different stages of the Rogun construction. It is not clear whether Uzbekistan is opposed to the construction in general or to a particular stage of construction.

The World Bank, and more recently the feasibility study of the construction company Lahmeyer International (Schmidt et al., 2006) did this and distinguished between different stages of dam construction. In Stage I, Rogun is supposed to provide an annual energy output of 5.6 TWh. For this purpose the height should be 225 m, with a total reservoir volume of 2.78 km^3, live storage of 1.92 km^3 and installed capacity of 1,000 MW. In Stage II, the dam height should be raised to 285 m (reservoir volume 6.78 km^3 and live storage 3.98 km^3) and in Stage III to 335 m (reservoir volume 13.3 km^3 and live storage 10.3 km^3) (Schmidt et al., 2006).

During the first 18 years of Nurek reservoir operation since 1972, practically the entire solid runoff of Vakhsh has accumulated in this reservoir with about 0.1 km^3/a. Since there is no significant lateral inflow between Rogun and Nurek reservoirs, the same average annual sediment deposition rate may also be assumed for the Rogun reservoir. Thus, after the commissioning of the Rogun dam, sedimentation at Nurek will significantly reduce, thereby increasing the remaining economic life-time of Nurek reservoir by at least 15 years (Schmidt et al., 2006).

2.2. DOWNSTREAM DAMS

2.2.1. *Tuyamuyun Hydro Complex (THC) – irrigational water supply*

The sole dam downstream of the Nurek reservoir is the Tuyamuyun Hydro Complex (THC), which is located 300 km south of the Aral Sea on the territories of Turkmenistan and Uzbekistan, and impounds the Aral Sea tributary Amu Darya. The complex (Figure 4) consists of more than 30 main hydraulic structures including four interconnected reservoirs: the Channel Reservoir (Amu Darya main stream), the Kaparas reservoir, the Sultansanjar reservoir, and the Koshbulak reservoir. Initially, THC had a total storage capacity of 7.8 km^3 but due to siltation losses, by 2001 the total storage was reduced to 6.9 km^3. Water from the THC is discharged to the lower Amu Darya and to an extensive canal system supplying the regions Khorezm, Karakalpakstan and Tashauz. The reservoir complex is used to redistribute the monthly water availability and the provided storage is mainly used for agriculture (around 98%), and partly for industry and drinking water supply (up to 2%).

Before 1979, there were only some natural depressions in the area of the current Tuyamuyun Hydro Complex (THC). During the period of 1981 to 1983, the construction was completed and the main stream of the Amu Darya was impounded at the section of the existing hydro-unit (dam structure).

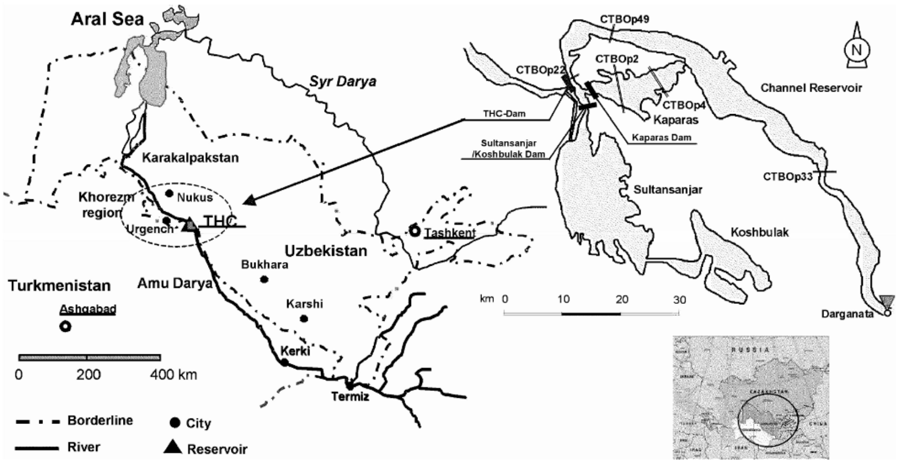

Figure 4. Location of the Tuyamuyun Hydro Complex (THC), with its multi-reservoir system and the inflow reference hydro post station Darganata, at the Aral Sea tributary Amu Darya.

The main THC dam is a concrete overflow dam with a height of 25 m, a total length of 141 m and a width of 41 m. Its main reservoir the Channel Reservoir, with a design capacity of 2.3 km³, is the largest reservoir of the THC. It is more than 102 km long, with a surface area of over 303 km² and a maximum depth of 20 m. The reservoir bottom has a design level of around 110 m above sea level (a.s.l.), and the normal pool level (NPL) elevation is 130 m (a.s.l.). The operation of the Channel Reservoir is characterized by water level variations between the maximum operating level of 130 m (a.s.l.) and minimum operating level of 120 m (a.s.l.). Within this range, the active regulation storage of the conservation pool is 2.1 km³, providing seasonal stream flow regulation of the lower Amu Darya. In total, all THC reservoirs are able to provide an operational storage volume of 5.4 km^3.

Channel Reservoir is built by impounding the natural riverbed, whereas Kaparas, Sultansanjar and Koshbulak are designed as off stream reservoirs. From Channel Reservoir the water is either channeled into Kaparas or Sultansanjar reservoir, discharged to the downstream part of the river, or enters the different irrigation canals. Water is also abstracted from Kaparas reservoir by a pumping station, with a current capacity of 5 m^3/s, and is used for the centralized supply of drinking water to the regions of Khorezm and Karakalpakstan with their main cities Urgench and Nukus.

Kaparas reservoir is connected to the Channel Reservoir near the THC dam by an open channel (Figure 5). Filling and release are controlled by one combined intake/outlet. Filling of the Kaparas reservoir requires a water level in the Channel Reservoir of over 117 m above sea level (a.s.l.) and lower levels within Kaparas in order to initiate open channel flow. The base of the Kaparas reservoir is 95 to 115 m (a.s.l.) and the normal pool level (NPL) is 130 m (a.s.l.). Operation is characterized by water level variations between the NPL and the minimum operating level of 118 m (a.s.l.) with an operational storage capacity of approximately 610 million m³, whereas the dead storage volume within the levels 95 to 117 m (a.s.l.) comprises 350 million m³.

Due to the expansion of the irrigated agricultural area starting in the time of the Soviet Union, the dams need to satisfy the generally increased water demand and especially the changed seasonal demand. Resulting annual variations of the stored water in the THC thereby become a problem. The THC is not designed to store water for multiple year requirements, so the operation of the whole THC multi-reservoir system under dry year conditions also has to address the monthly redistribution of water deficits.

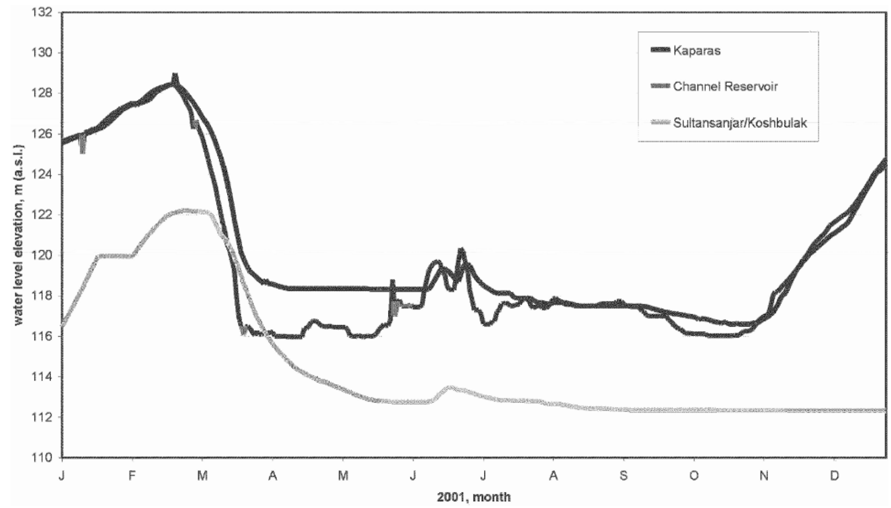

Figure 5. Reservoir operation of the Channel Reservoir, Kaparas, Sultansanjar and Koshbulak during the dry year (2001), water level elevation m (a.s.l.).

3. Potential of dams for improving future water supply

3.1. NUREK

Comparing the impact of the Nurek reservoir releases with the downstream inflow into the Tuyamuyun Hydro Complex, it becomes evident that the effect is minimal. Figure 6 compares the daily outflow of the Nurek reservoir with the inflow to the Tuyamuyun Hydro Complex (THC) at the reference station Darganata (120 km upstream of THC). During the summer flood (between April and August) the releases from the Nurek reservoir are in the order of magnitude of 20% of the total discharge at Darganata station for average water years such as 2003 and 2004. From August, the contribution the Nurek releases to the discharges at Darganata increases to more than 50%. Nurek's releases for hydropower purposes represent proportionally more than 60% of the discharge at Darganata station, between September and April. Hence, in terms of irrigation, the water from the Nurek reservoir seems to be utilized mainly for the last seasonal irrigation and the off-season leaching period of the downstream riparian states.

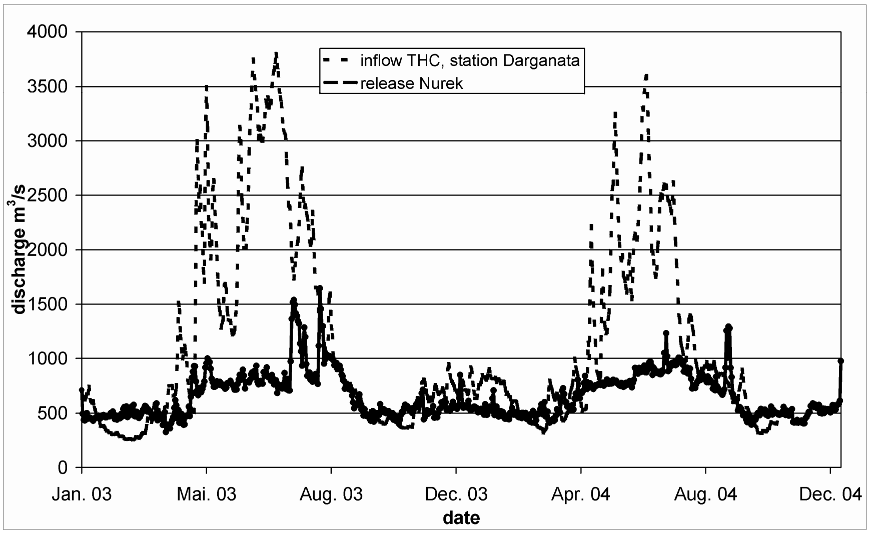

Figure 6. Water releases of Nurek reservoir and the impact on the water inflow to the THC reservoir system downstream, 2003–2004.

To make up for electricity shortages during the winter period, Tajikistan is expected to change the mode of operation for the Nurek dam. As argued, Nurek's summer releases do not contribute significantly to the total flow, and therefore it is questionable whether a small change in the mode of operation will have a significant influence on downstream agriculture. Until now, Uzbekistan has not perceived the potential changes to the Nurek releases as a threat (Wegerich et al., 2007), assuming that a modification of the releases will only have a minor impact. Although the impact might be small, it is questionable whether even a small change would be appropriate given the political tensions in the region.

3.2. ROGUN

Utilizing the Nurek in combination with the Rogun dam could be a win-win solution for downstream and upstream countries. It would guarantee

Tajikistan's energy requirements and at the same time, it would enable Tajikistan to continue to facilitate the agricultural production of downstream riparian states. Furthermore, Stage II of the Rogun dam could be seen as a safety measure for times of water scarcity or drought. During a period of drought, additional releases from Rogun could increase the available water for downstream urban and agricultural users. It appears that, with the additional dam, the benefits to all the riparian states could be increased.

Rogun not only will be of high interest for the power production, but has also significant positive effects on siltation and storage capacity losses of the existing downstream reservoirs. Due to sediments held back by Rogun dam, the life-time of Nurek, which is located 70 km downstream of Rogun, will be substantially prolonged (Schmidt et al., 2006).

3.3. ENHANCED THC MANAGEMENT

At the lower part of the Amu Darya, in principle the THC reservoirs provide insufficient storage capacity for keeping a strategic reserve to cover water deficits and irrigation demands during dry years. Nevertheless past project results indicate interesting options to reduce the water deficits and to increase simultaneously the possibilities for a safe drinking water supply only by modifying the operation regime. As one out of four large reservoirs and an off-stream reservoir, Kaparas reservoir could be increasingly used for drinking water supply for the lower Amu Darya region.

The concept of enhanced reservoir operation is understood to mean changing time and volume of filling, storage, and releases to minimize the blending of high quality water stored with low quality inflowing water. Multi-reservoir systems can be used to store waters of different quality in different reservoirs and hence maintain high quality water in at least in one reservoir to secure drinking water or irrigation water for sensitive crops.

Analyses of the different reservoir operation policies has shown that the conventional operation regime currently used during dry conditions is mainly based on filling the Kaparas reservoir with highly saline water during the winter months. Schedules do not consider the potential for storing high quality water, which is available during the low saline summer floods, even under dry year conditions, when comparably low salinities between 800 and 1,000 mg/L can be expected. Basically, this is determined by the need to transfer water from the low saline summer flood to the downstream irrigated areas. Another important constraint is the need to fill Kaparas using even higher water levels in the Channel Reservoir.

In contrast to conventional operation, the results of the enhanced reservoir operation strategy (Figure 7) demonstrate an improvement of both the water quantity and water quality in the THC reservoirs. It shows the capability for improved water availability in the lower Amu Darya region and provides a reduction of the regional annual water deficit up to 54% (2.3 km^3/a). Furthermore, the results for the drinking water reservoir Kaparas have demonstrated a possible reduction of salinity concentration of 35%, falling below the WHO standards even during just 1 year of enhanced operation, and an accordant reduction of 62% after a 2 year application as well.

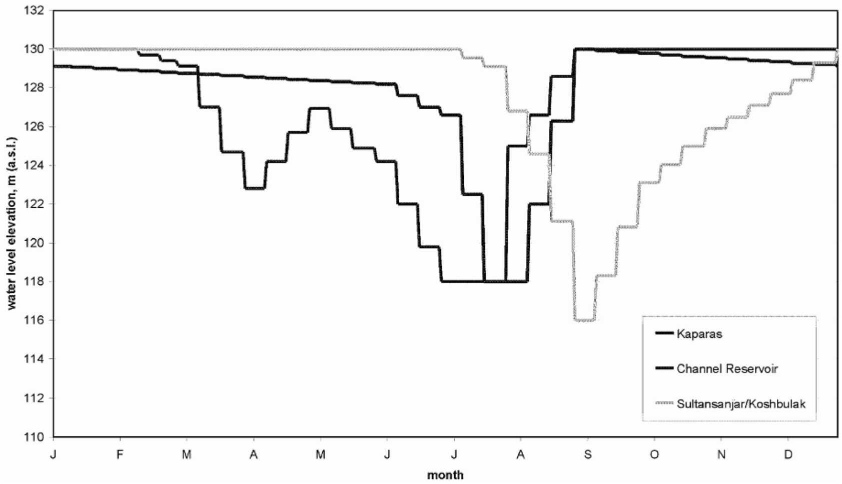

Figure 7. Developed water level elevation (m, a.s.l.) of the THC reservoirs under dry conditions.

4. Conclusions

It is of critical importance for the Amu Darya basin to use existing infrastructure in a better way and adapt the water allocation accordingly, especially during dry years. Hereby, the large dams and reservoirs of the region play an essential role as they provide the potential to act as an instrument for adapting to ongoing water shortage caused by global change.

In particular the downstream reservoir complex THC offers more opportunities in this context than the other dams, Nurek and Rogun. This is due to the fact that the Rogun reservoir is unfinished (so far without any prospect of completion), and the Vakhsh River does not represent the main water source for the downstream area of the Amu Darya.

In principle, the Nurek reservoir controls only a considerably small proportion of the annual water available from the entire Amu Darya and therefore the interdependence between upstream control and downstream utilization is definitively less than commonly argued. First, the Vakhsh River contributes only partially to the total annual runoff of the Amu Darya.

Second, the water level at the Nurek reservoir is only regulated between 910 m (a.s.l.) and 857 m (a.s.l.), corresponding to a theoretical active storage of 4.7 km^3. Even if currently the reservoir is refilled during the summer months, first information available indicates that nevertheless a part of the inflow originating from snow and glacier melting is released downstream.

The situation would have been different if the anticipated construction of the Rogun reservoir had been completed under the Soviet regime. The plan to recommence the construction of the Rogun dam reflects that neither Stage I nor Stage II would put Tajikistan in full control of the Vakhsh basin, because the live storage is still below 40% of the mean annual flow. It is only in Stage III that this would occur but will not have a serious effect for the downstream users, because the Vakhsh River contributes only 25% of the total Amu Darya flow.

The continuation of the Rogun dam construction is not only a matter of financial capabilities. Further issues are also the difficulties to alter important road connections to the eastern parts of Tajikistan and to agree on sharing costs and benefits from the hydropower generation. As long as such basic questions are not solved, it is difficult to investigate the effects of additional storage capacity to cover water deficits during dry years.

The existing reservoir complex of the Tuyamuyun Hydro Complex offers the greatest capability for an adaptation of management strategies. Enhanced reservoir operation for the reservoir complex has been verified as an effective measure for a rapid and comprehensive improvement of the water quality in water crisis regions. The possibility to adapt the operation rules has been demonstrated by the potential of the THC to supply the local population (of the lower Amu Darya region) with more potable water of higher quality even subject to a parallel reduction of water deficits.

However, the current rational management of transboundary water resources in the Amu Darya basin is still hampered by the difficulties to increase both the quantity and reliability of hydrological data (including information on water consumption and operation regimes) and to predict the short and long term availability from the glacier run-off. Major uncertainty has been also identified regarding knowledge of current sedimentation processes and expected capacity losses of the dams for the future.

The development of sustainable management strategies for securing future water supply in the Amu Darya region needs (i) to revise the existing storage capacities, (ii) to collect confident and reliable data and information on hydrology, drainage efficiency and snow accumulation in the valleys, (iii) to improve forecasting methods, (iv) to associate possible water saving mechanisms and improved crop growth patterns in the downstream areas, and finally (v) to adapt the dam operation in upstream and downstream regions accordingly.

Only with progress in these areas may more tailored operation regimes be investigated and proposed for the discussion both at state and interstate level.

Acknowledgement

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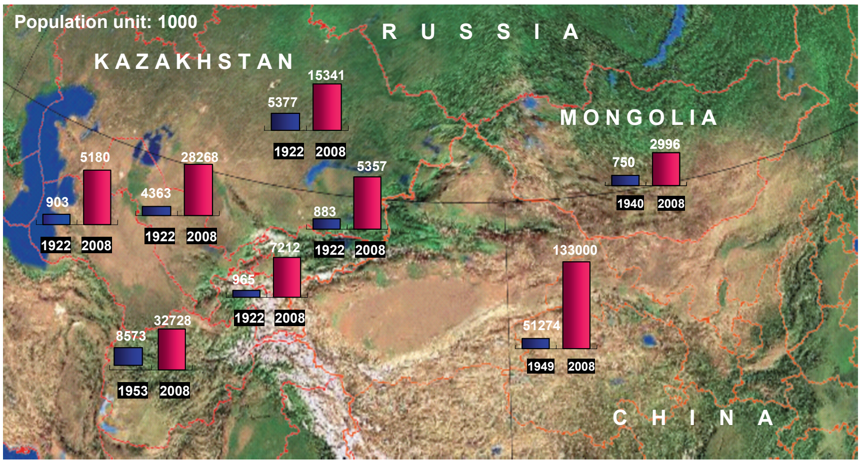
Part IV

Political Economy and Governance



Population changes in Central Asia.

POPPY ECOLOGIES AND SECURITY IN EURASIA: LESSONS FROM TURKEY'S PAST AND PRESENT

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Abstract. In Turkey, legally cultivated poppy fields yield a cash crop that is essential in the rural livelihoods of particular households and communities. Licensed farmers are able to earn far more from harvesting both poppy seeds and the remaining opiate-containing capsules that are sold to the state for use in the medical morphine industry than from any other crops. Although the cultivation of poppies in Turkey was once used for opium and heroin, among other commodities, a controlled reintroduction of poppies occurred in the 1970s following a nation-wide eradication program. Though the eradication program may be critiqued due to its geopolitical contexts and goals, the subsequent reintroduction of poppies and the emergence of this legal industry established a basis for ecological and economic stability at the scale of local communities. Moreover, for many Turkish farmers and others, it was regarded as a step towards the promotion of democracy at the scale of the nation-state. Relying on both fieldwork and archival research, this chapter looks at the historic and contemporary examples provided by Turkey and considers the ongoing challenges posed by poppies in the case of Afghanistan. Based on this review of these two different situations involving poppies, it is suggested that Turkey's instance provides powerful lessons for policy makers seeking to promote both security and sustainability throughout Eurasia and in Afghanistan, in particular.

Keywords: Poppies, opium, political ecology, sustainability, security, Turkey, Afghanistan, Eurasia

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1. Introduction

This chapter, based on both ethnographic fieldwork and research with archival and government documents, examines the varied ecologies and geopolitics of poppy, or opium, production in Turkey. Integrated thoroughly in centuries-long global geographies of opium manufacture and trade, Turkey was compelled in the 1970s to eradicate its involvements in both. In a Cold War geopolitical context comprised both of strong pressure from the United States at a global scale and of a military-led administration in Turkey at the national scale, an eradication program was adopted. Criticized both as a policy emanating from Washington, DC – and not Ankara – and as a policy resulting from military rule – and not a democratic state, the issue of poppies was politically relevant in the electoral politics that ensued with the planned restoration of democracy, and promises to reintroduce the crop – albeit in a controlled context – were realized. Since that time, the crop re-emerged as a government-controlled enterprise that benefits both the state and legally authorized producers found in local villages. Though we might note the contemporary ironies of how the crop re-emerged as a successful legal commodity at local levels while simultaneously confronting the state at national and global scales as Turkey finds itself to be one of several key transit states for the illegal trafficking of opium/heroin that is produced beyond its borders (esp. in Afghanistan), this initial survey in an ongoing research project on major themes in these historic and contemporary geographies of poppy production and trade in Turkey does point to the profoundly successful re-introduction of the crop at scales both local and national. In this regard, this case study of the Turkish experience has profound relevance for contemporary challenges posed by illicit production of the crop in Eurasia today, in general. In particular, it is a work that also offers lessons for immediate consideration in those places currently confronting dilemmas associated with issues both of security and of crop eradication and/or regulation – most notably Afghanistan.

In order to illustrate the significance of this sustainability- and security-building experience in Turkey not only for academic study but also for its profound relevance to some of today's ongoing, real world challenges, this analysis begins with a brief examination of the opium poppy in the Mediterranean and Eurasian regions up through the early 1970s. The experiences of the 1970s in Turkey will then be addressed in terms of the politics of both eradication and reintroduction of the poppy. This historical survey based on a reading of the historical record in archival and secondary sources is then complemented with my own ongoing fieldwork in local poppy-producing communities of rural Turkey. As informed by local voices and observations, this ethnographic and geographic research into the role of poppies in rural Turkey today renders vivid lessons in terms of poppy-growing communities with regard to both their ecologies and political economies. The chapter then raises the current predicaments posed by illicit poppy production in Afghanistan, and it concludes with both a discussion of how lessons from Turkey's past and present might alleviate – though clearly not solve in the immediate future – some of the problems associated with poppy cultivation and the transnational manufacture and trafficking of opium/heroin.

2. Poppy cultivation and opium in the Mediterranean and Eurasian regions prior to the 1970s

Domesticated in the Mediterranean region (note Booth, 1996; Kapoor 1995; and Merlin, 1984), opium poppies (*Papavar somniferum*) have a long history of cultivation in Turkey for their flowers, their seeds, and especially for the opiates found in the plants' capsules (as historically analyzed and presented in Evered, 2006, 2007a and 2007b). Often found to be thriving in otherwise marginal soils and requiring relatively little water, this crop that seems so ideally suited for the lands of Anatolia – and for the wider arid ecosystems of the Mediterranean and Eurasian regions – has also provided peasant farmers, past and present, with levels of income that would be quite unimaginable for any other crop planted on similar acreage. Thus, despite the fact that their harvests would eventually contribute to the global trade in opium and heroin, Anatolia's farmers had always had powerful ecological and economic incentives to contemplate growing poppies. Amid my own ethnographic research in the poppy growing region of Turkey today, I attempted to get a sense of the history of opium in the region when I asked various farmers, "When did people begin cultivating poppies in this region?" The response from one retired farmer to this question summed up how the crop is viewed as inseparable from local popular understandings of the region's history; looking at me as if I asked something painfully obvious, he said, "We've always had poppies/opium here."

Centuries before the eleventh-century arrival of Turkic peoples in Anatolia, poppies figured into both the ecologies of local communities and the region's networks of trade. Apart from the medicinal and/or narcotic applications of poppies, the plants were valuable components in the region's culinary cultures as they yielded seeds that went into oils, pastes, and baking. Though I have never personally witnessed or heard of such use from retired and current poppy farmers in Turkey today (something I have repeatedly tried and failed to verify – some farmers even stating it would make their animals ill), some historical sources (e.g., as cited in Poroy, 1981) even attest to the use of the remaining seeds and seed byproducts – and even flowers and leaves – as fodder for farm animals. Moreover, the tall stalks of the plants that would be cleared from the fields each year after harvests were used not only as an immediate source of fuel in cooking and home stoves, they also were incorporated into local construction activities, either being used in brick making or as roof thatch for homes in the region.

The cultivation of poppies is not an inherently labor intensive activity by any means – so long as certain precautions are taken to avoid excessive moisture and cold temperatures. However, traditional means of both cultivation *and* extraction of the opiates from the poppies certainly was/is labor intensive – at least during peak periods of the late growing season when the poppies' capsules are cut to allow for collection. This intensive demand for essentially harvesting the opiates from the poppies is one factor of traditional production that kept the on-the-ground scales of production low in the Turkish case, generally limited to individual households that would plant on only four to five *dönüm* of land (Erhan, 1996; note that, according to the *Redhouse Turkish Dictionary*, one *dönüm* was only about a quarter of an acre).

With the spread of not only the Ottoman state but also European empires, the opiate extracted from poppies emerged as a global commodity with not only economic consequence but also with profound geopolitical significance. Amid these developments, we saw an increasingly eastward shift in the geographies of cultivating poppies for the global opium market (esp. to South Asia and, later, to Southeast Asia). Nonetheless, Ottoman Turkey continued to produce and profit from opium up to the time of the state's collapse in the early 1920s. Indeed, opium from Anatolia – and not just India – was ending up in China as Britain encouraged greater consumption of – and addiction to – the drug in East Asia. Most of the Anatolian opium shipped eastward aboard British and American ships was thus destined for the coastal areas of China and Malaysia.

Commenting on opium production during the nineteenth century – with the exception of only about a decade in the 1820s and 1830s, one historian noted, "opium touched everyone" (Poroy, 1981, 196) in Anatolia. In the context of the Ottoman Empire's multi-ethnic, multi-linguistic, and multi-religious society, this characterization included Armenians, Greeks, Jews, and Turks, among others. This escalation of impacts from opium production and marketing was especially so from the 1840s onward, as demand for particular grades of Anatolian opium were increasingly esteemed for pharmaceutical consumption and not just for smoking. The global preference for Anatolian opium may also account for why people were willing to engage in the more cumbersome endeavor of shipping it from the Mediterranean region to East Asia rather than simply growing more in South or Southeast Asia. Escalating consumption in the West of opium and morphine also contributed to the rising global demand for shipments from Anatolia. As global demand increased, so did areas under cultivation – both in terms of the limited space on smallholders' individual farms and especially in terms of the wider geographies of poppy cultivation of Anatolia (ibid.).

Already a commodity with a wide geographic spread and deep cultural roots in places as far off as China (e.g., note Zheng, 2005), states that could master the logistics of opium production and marketing (i.e., Europe's global empires) had the most to gain. This association of opium with empires is the stuff of popular histories (e.g., Hanes and Sanello, 2002), and though most Western empires fought for and profited from opium trade, we especially think of the case of Britain and China in envisioning how the relations of empire were inseparable from narcotics in particular contexts – even fueling wars and stimulating territorial annexation and colonization. The consequences of such experiences created many legacies for the nation-states that would emerge in East and Southeast Asia (e.g., in the case of China, note Baumler, 2007).

Increasingly characterized as the "sick man of Europe" throughout the nineteenth century by Westerners, the Ottoman state – which had been confronting a centuries-long period of steady decline in terms economic, political, technical, and territorial – sought to bolster its fortunes by establishing a "monopoly" over opium in the late 1820s. Clearly emulating the British example of control over the crop and its trafficking, this attempted "monopoly" intended to restrict the rights to purchase opium from producers. With only the state's own representatives and also those firms sanctioned to act for the state having permission to purchase opium, the empire was creating what was really more a state-run monopsony (and not a "monopoly" – as it is labeled in both historic documents and the current literature) that would have exclusive rights of purchase, and thus also the ability to dictate the prices paid for opium. The Ottoman institution established for this purpose, the *Afyon Tekeli İdaresi*, would not only create advantages for the Ottoman state in the buying of opium, it was also intended to establish and administer taxation of opium production and trade. As with many Ottoman attempts at reform in the nineteenth century, however, this effort failed due to both internal limitations and external pressures. The Ottoman state lacked both the financial resources and the personnel to purchase all the opium when it came available immediately following harvests. Additionally, the British Empire was in a position to demand that the Ottoman Empire end its attempts at a monopsony through the August 1838 Balta Limanı Treaty (for a full text of the treaty in English, see Khater's 2004 textbook of translated historical documents, 48–51). Throughout the nineteenth century, the declining Ottoman Empire continued to rely upon opium as one of the major revenue-generating exports that its economy could depend upon. Though not the greatest source of revenue for the Ottoman economy, based on my own review of 1880s and 1890s Ottoman fiscal annuals, it was certainly the highest priced of all agricultural commodities by volume. Understandably, Ottoman Turkey largely avoided participation in the international efforts towards dealing with narcotics that began to pick up momentum in the early twentieth century, largely under the leadership of the United States. Only with Turkey's signing of the Treaty of Sevres did the state agree to comply with the international agreements emerging since the turn of the century.

Following the demise of the Ottoman Empire and the War of Independence, the newly established Republic of Turkey inherited most of the Ottoman state's debts. In this early 1920s context of a nascent Turkish state with a fragile economy, the production and export of opium remained a valued source of revenue. This tenuous economic state of affairs also meant that there was very little (i.e., nothing) to invest in poppy production, so the means and the scales of production remained virtually the same (i.e., household labor on small-scale family farms).

By this time, however, most exports were destined for Western countries, eventually ending up in France, the Netherlands, and the United States, among others. Even in the final years of the Ottoman era, public attention in Western Europe and the United States began to focus on the problems of addiction from opium and morphine. In this context, images of Ottoman and republican Turkey as a significant source of opium – and eventually heroin – began to enter into American stereotypes. During the late-nineteenth and early-twentieth centuries, Americans also identified East and Southeast Asia as regions of even greater risk to the United States. As a consequence, some of the United States' earliest anti-narcotics campaigns focused on Asia and a good deal of anti-Asian immigration rhetoric contained references to opium consumption and trafficking.

Within Turkey, though ecologies and local relations of production remained much the same in the transition from empire to republic, the state did attempt to limit processing of opiates after a number of foreign interests began manufacturing operations in Istanbul not for morphine but for heroin. The new republic passed law #1369 in December 1928, the state's first example of legislation attempting to control narcotics. This law sought to regulate all aspects of production and sale of any drugs and charged the Ministry of Health and Social Services with oversight. Though it is easy to view this move as simply a measure geared towards assuaging pressures from the West – and especially from the United States, the rising levels of drug abuse within Turkey (esp. in Istanbul) and the incidence of addiction-related crimes that ensued were more likely factors in prompting this legislation. Indeed, Turkey continued to avoid signing on to the 1925

Geneva Opium Agreement – a position that would remain a theme in US-Turkish relations for decades to come (note discussion of this period in Erhan, 1996). Within Turkey's poppy-producing communities, little changed until the 1960s and 1970s.

3. Poppy eradication and reintroduction, the 1970s

Though it is often depicted as stemming entirely from United States pressures in the early 1970s, Turkey did begin to attempt to assert greater control over poppy cultivation as early as the 1960s – due to external *and* internal factors. Most notable was the increasing restriction of where poppy cultivation would be permitted within Turkey. Though such measures even occurred during the Ottoman era, generally they were more motivated in the past by concerns over securing effective tax revenues for the state rather than matters of narcotics control. In the Cold War era, however, Turkey was increasingly identified by the United States as its major provider of heroin. Though exact estimates would vary by source and year, it was generally noted in most American accounts through this era (up to the 1970s) that, although it only cultivated roughly 15–20% of the world's narcotics-producing poppies, Turkey was the supplier of roughly 75–85% of the heroin that would eventually enter the United States. While a great deal of global attention was thus focused on the so-called French connection (i.e., poppy fields in Turkey, heroin-processing in Marseilles, France, and eventual markets in New York), in truth, an ever-increasing proportion of heroin entering the United States was instead emanating from Southeast Asia (for a thorough historical account of these geographies of narcotics production and trafficking during this period – especially in terms of Southeast Asia and the role of the United States, note McCoy, 2003). Such claims regarding Turkey's involvement in supplying the United States may have resulted purely from ignorant speculation, or they may have been attempts at obfuscation – motivated by either the fact that the United States involvements in Southeast Asia actually fostered (even promoted and profited from) the drug trade or speculation that a United States "war on drugs" in Turkey (a NATO ally) would prove more winnable than any such attempts in Asia. Regardless of causes – or potentially surreptitious motivations, such figures – though still cited in numerous studies on histories of poppies and narcotics – are regarded largely as entirely overblown. Additionally, though challenges to the accuracy of these figures have been made consistently within Turkey, but rarely do we see aspects of this debate in the English language literature (for an ideal statement, see former Prime Minister Bülent Ecevit's forward to Erhan's excellent 1996 study). Nonetheless, arguments about the scale of trafficking aside, heroin was coming from Turkey, and it was entering the United States.

Though the will for absolute eradication of Turkish poppy cultivation existed among United States politicians, the means for achieving such a goal did not exist until Turkey's March 1971 military coup. With a military-led administration of the country – a military that was greatly dependent upon its connections with NATO and the West, the President Nixon's administration and the United States Congress pushed Turkey for total eradication of the crop. In promoting this policy, the United States employed carrot and stick incentives with Turkey – threatening to withhold military aid while also pledging monetary assistance to compensate farmers. In Turkey, however, this was an enormously unpopular development. In the eyes of the growing number of critics of the military-led state, this move was seen as an act of imperial-like pressure on the part of the United States, a profound symbol of a lack of democratic leadership in the country, and an outright victimization of Turkish farmers (this sentiment is quite apparent in the two excellent Turkish books, Erhan, 1996; and Altındal, 1979).

Resulting in the elimination of the "French connection," overall global supplies of heroin were not greatly affected, as illicit cultivation in areas such as the "Golden Triangle" (i.e., Southeast Asia) and the "Golden Crescent" (i.e., South/Central Asia – esp. Afghanistan) were already increasing to meet growing global demands. Within Turkey, local farmers and their communities were greatly impacted in the short-term – until aid for compensation could be delivered. In reading United States congressional reports from this era, farmers' levels of dissatisfaction were considerable and they felt abandoned with few viable options (e.g., in one such report, a farmer complains how the suggested substitute of sunflowers were entirely undesirable with regard not only to income but also local tastes and preferences for poppy seed oil and unfamiliarity with sunflower seed oil – underscoring problems with crop substitution that are equally pertinent in cases of attempted anti-drug campaigns today). To the Turkish state's credit, the majority of funds sent from the United States did eventually make their way to Turkey's former poppy farmers. Although oral histories on this period that I have collected from the region in recent years sometimes incorporate a longer-term view (e.g., past and present poppy farmers commented that some in their communities "got rich" – at least by village standards – from *not* planting poppies once compensation arrived), the short-term suffering is evident in the historical record and in such oral accounts, upon deeper questioning about the specific period.

Given this profound unpopularity of poppy eradication in Turkey – both among villagers themselves and the many others in Turkish society who sympathized with them, the matter of poppy cultivation became an especially important political issue as politicians were preparing for a return to democracy in their country. In the 1972 elections that followed, the populist candidate Bülent Ecevit emerged as a favorite of many farmers due to his pledge to permit them to return to sowing their fields with poppies – albeit in a tightly controlled manner that would only supply opiate-containing products for medical morphine produced by the pharmaceutical industries in Turkey and abroad. Viewed historically, what seemed at the time to United States commentators as populist politics run amuck, the reintroduction of poppy cultivation resulted in restoring ecologically and economically sustainable ecologies to a developing country. For many in rural, agrarian Turkey, the return of poppies was symbolic – if not tangible proof – of the republic's return to democracy. This view that poppies were/are democracy was abundantly apparent not only in my reviews of Turkish media discourse of the 1970s but especially in the conduct of my ongoing fieldwork among some of Turkey's communities of poppy farmers.

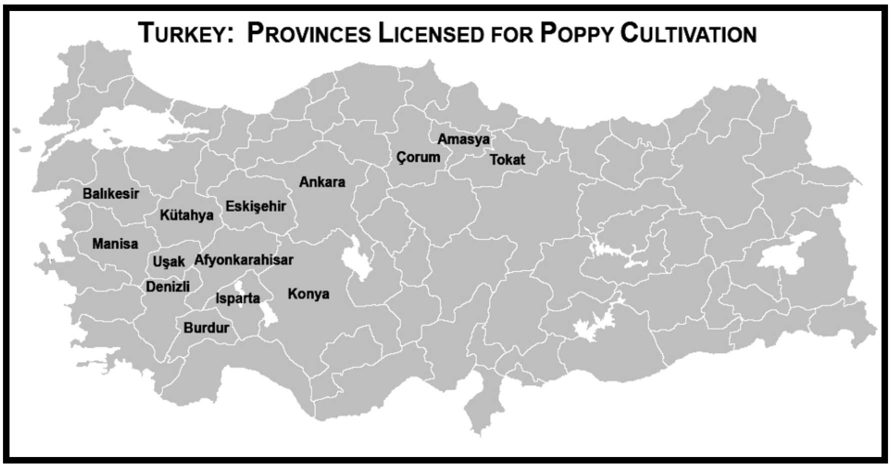

Figure 1. Turkish provinces where poppy cultivation is permitted.

In reintroducing poppy cultivation, permission has only been granted to farmers in fourteen of the country's provinces (see Figure 1). Though cultivation was once found almost throughout the country, contemporary geographies reflect generally an emphasis on areas where it was traditionally preferred. These patterns may also be regarded as reflecting enforcement practicalities, however, as the other provinces previously favored in Ottoman and early republican eras were in Turkey's southeastern region. Additionally, some interviewees speculated that continued cultivation in areas of lesser productivity (i.e., the north-central provinces of Amasya, Çorum, and Tokat) might be more reflective of past/present appeasement of particular constituencies, given the obvious disparities when compared with other provinces (note contemporary levels of productivity indicated in Figures 2 and 3).

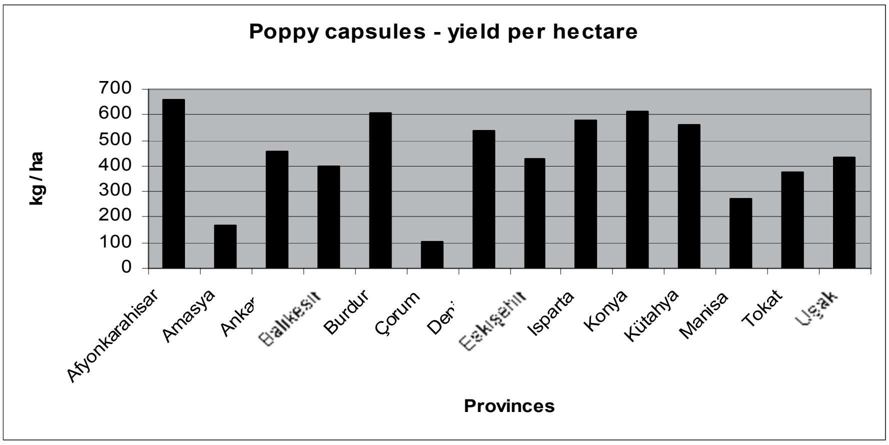

Figure 2. Poppy capsule average yield per hectare by province, 2005.

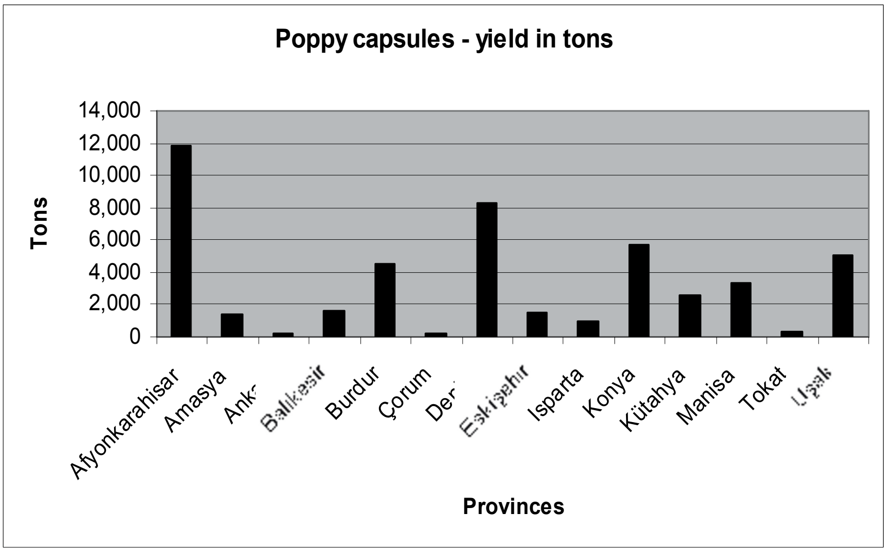

Figure 3. Poppy capsule yield in tons by province, 2005.

4. Political ecologies of poppy cultivation in Turkey today

Because much of the story about Turkey's past and present geographies of poppy production has been told solely from perspectives of either the United States or peoples found in Istanbul or other cities (e.g., politicians, journalists, and academics), the voices of farmers have remained largely unheard. Given this problem, most of my own ongoing research has involved dealing with that aspect of poppy cultivation in Turkey that is "local" (i.e., rooted in the ecologies and economies of farmers' households, their fields, and their villages). Last summer, while I interacted in a central area of a town that I visited with a farmer whom I rely upon for insight and explanations about farming and regional histories, a local politician asked what lessons I was teaching to him. The official seemed surprised when I responded, "I am not teaching him anything at all; regarding farming and the environment, he is my professor." While this exchange seemed amusing to some of the people there at the time, it reflects the challenges that small-scale agriculturalists continue to face in Turkey today.

In working with local farmers of poppies, it is abundantly clear that none of them are rich, but they generally do have a slightly better standard of living than do many of the peasant farmers that I have encountered who do not grow the crop. In most instances, the farmers rely on at least one additional source of income, as well (e.g., dairy farming – almost always at a scale of less than ten milking cows, aniseed, sugar beets, or roses – especially in Isparta, among others). Moreover, the farmers are also driven not only to earn money but also to save it; household gardens are essential, as are fields for growing their own fodder for any livestock that they may have. In most of the meals that I was invited to in the area, the only items coming from beyond the household and village economies were products such as tea, coffee, or other items.

With specific regard to poppy cultivation, each farmer granted a state license must be a landowner. Plots for cultivation (like the seeds to be planted each year) are stipulated by state officials, and the plots are rotated by state orders among each farmers' various small-scale holdings (a common feature in the tenure arrangements of many of the farmers that I have worked with), at least partially to aid in shifting sites for better purposes of policing. This rotation is not an inconvenience for local farmers, as they note that it has always been their practice in the region to allow areas to go fallow for 1 or 2 years before replanting with poppies – unless they were willing to commit to the expense of resource, time, and possibly money for fertilization.

The sizes of cultivated fields are also generally small in area; only about one to two acres. The sizes are no longer a reflection of the labor-intensive demands for poppy/opium harvesting. Indeed, Turkish farmers today do not incise the poppy capsules in the springtime while they are still green in order to repeatedly scrape the opiate-containing liquid that would seep out. This is because the farmers today wait approximately 1–3 extra months – until about July. By this time, the poppy capsules are quite dried out, with the seeds rattling inside. In a matter of a few hours, a family can walk through their field and collect all the capsules that easily break from the stalks. This manner of harvesting also aids immensely in policing; if people had been slicing the capsules to extract opiates for opium/heroin production, the scaring of the otherwise bright green springtime capsules and the brownish to blackish color that the white liquid turns to as it dries on the capsule prior to collection are immediately apparent to anyone walking past a field.

The gathered dry capsules are then smashed – usually by small machine, and seeds are separated from broken capsules. The seeds are the farmers, and they are used for local consumption in baking, or in making oil or a paste – one that has a flavor not unlike some varieties of organic peanut butter. The seeds also provide valuable revenue for the farmers as they are also sold. The remaining capsules – which contain the plants' opiates, are collected and turned over as they are sold to the state. Depending upon the area planted, its conditions, and anticipated annual levels of productivity, farmers are required to sell certain weights of the smashed capsules back to the state. Indeed, they have no incentives not to sell to the state, as it is the only buyer for capsules that must be processed in a factory.

In this experience of controlled reintroduction, both economic and ecological sustainability have been achieved and political security has been fostered. Though the farmers of the area are also very proud to point to their own experiences as successes over time, it is important to note that the risks that many fear the most today do not come from eradication. Rather, many of the farmers that I have worked with express grave reservations about the neoliberal development and restructuring plans undertaken by the current Turkish state – initiatives encouraged by the IMF, World Bank, and European Union. Such plans have thus far been viewed as very detrimental to Turkey's small-scale farmers, its biodiversity, and environment, and the consequences have been a growing number of protests.

5. Poppies and insecurity: Afghanistan today

Despite President Hamid Karzai's widely reported declaration of a jihad against opium in December 2004 (MacKenzie et al., 2006), poppy production has continued to increase in Afghanistan ever since the late-2001 demise of the country's Taliban state. In 2001, following the Taliban's own selective eradication, the area of the country's territory devoted to poppy cultivation was at an all time low of 8,000 ha. By 2005, this figure was at 104,000 ha, and in 2006 it increased to 165,000 ha – a 59% jump in just 1 year. According to the United Nations, this increase in area would enable Afghanistan to potentially provide for up to 6,100 t, or 92% of the world's total supply of opium in 2006. In demographic terms, it is estimated that 2.9 million farmers, or 12.9% of Afghanistan's population, are now growing opium poppies (UNODC, 2006, 1–28). The percentage of Afghanistan's total population that is dependent on revenues from poppies is far higher when we consider household size and the numbers of people who work as non-farmers in support of this national industry. Crops have even grown so large in recent years as to require the hiring of migrant workers in some of Afghanistan's highest producing provinces, most notably in Helmand (Sarhaddi Nelson, 2007). Though this boom in production has led to a drop in prices for opium in Afghanistan and beyond, potential revenues are still many times higher than for wheat, sunflower seeds, and other legal alternatives that have been suggested.

In addition to the resurgence of illicit poppy cultivation as a problem unto itself and associated problems of corruption that undermine the Afghan state and permeate beyond its borders throughout the region, profits deriving from this industry continue to aid in resuscitating Taliban and al Qaeda resistance both to the Karzai government and to the combined NATO- and US-led coalition force. Moreover, this situation has also further enabled a rapid rise in local abuse of illicit drugs (UNODC, 2005), essentially disproving the commonly held assumption found both in the region itself and in the West that supposes that narcotics producing states with Muslim populations do not encounter problems with drug abuse – an assumption also disproved from the afore mentioned example of late-1920s abuse in Turkey.

Prospects for any absolute eradication of poppies in Afghanistan are improbable. On one level, we arrive at this dismal forecast simply by noting the sizable percentage of the country's impoverished population that is directly dependent upon revenues earned from growing or otherwise working with the crop. At this level, dependency on poppy production exists due to two factors; there is an absolute lack of alternative sources of comparable income in most parts of the country, and there is a constant demand for heroin internationally. On another level, one that focuses not on the local-global connections but instead on the operative realities of the Afghan state's political economy, this forecast exists due to factors that are well beyond any simplistic economic imagery that might depict needy peasant farmers struggling to feed their families at one end of a commodity chain and Westerners with an insatiable demand for narcotics at the other end. Indeed the bleak forecast for eradication also derives from what a growing number of observers (e.g., note Risen, 2007 and the subsequent record of testimonies before the United States Congress) concede is the geopolitical reality of Afghanistan amid occupation; the same Afghan state that pledges to fight opium with a religious zeal – or at least a substantial component of both its national and regional leaders – is reliant simultaneously on internal interests, relationships, and funds that derive from the narcotics trade.

6. Summary and conclusions

It would be overly optimistic to assume that the present Afghan state could imagine any absolute eradication of or complete shift to legal poppy cultivation, as was achieved in Turkey, yet the Turkish case offers great insight as to how the problem might begin to be addressed. In all journalistic, congressional, and United Nations accounts thus far, it is clear that those Afghanis most affected by eradication attempts are small-scale peasant farmers. Their fields are targeted routinely for destruction – either for show or as retribution for not compensating particular local interests, just as nearby poppy fields of the wealthy are left alone. Because alternative crops' revenues are far less and their necessary inputs are often far more expensive, peasant farmers do have incentives to police their fields and make only legal sales – if their fields could be guaranteed protection from eradication. Like the Turkish farmers, they could profit from both seeds and capsules, and revenues from subsequent processing and export for pharmaceutical applications would go to the state's formal economy and not the informal narcotics economy that benefits insurgents. Finally, this cultivation is also ecologically sustainable, requiring neither the irrigation schemes nor the other inputs of alternative crops.

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DISTRIBUTIVE CONSTRAINTS ON ENVIRONMENTAL POLICY IN CENTRAL ASIA

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Abstract. This paper addresses the importance of distributive issues for environmental policy-making in Central Asian countries. Environmental problems in Central Asian countries are severe and require non-marginal policy interventions. Non-marginal interventions, however, are likely to lead to significant negative economic impacts on well-defined groups of people within Central Asian societies. The paper argues that distributive issues merit consideration in the process of policy-making. Implementing policies that neglect those negatively affected by them can lead to outcomes that are ultimately undesirable from a social perspective. Distributive issues therefore impose additional constraints on environmental policy and are likely to be salient features in Central Asian policy-making over the short to medium term.

Keywords: Environmental policy in Central Asia; economics; distributive issues; conflicts; efficiency

1. Introduction

In Central Asia, as elsewhere, environmental policy is about generating social welfare gains through improvements in environmental quality. A number of constraints exist, though, to realizing these welfare gains. Due to their level of economic development and the nature of their governance systems, it is clear that countries in Central Asia face constraints that are particularly binding for policy-makers there. Among the many factors that determine these constraints, this paper focuses in particular on the

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distributive impacts that policy solutions to environmental problems in Central Asia entail.[1] The paper will argue that these impacts are of special relevance since policy measures to address environmental problems in Central Asia will by their very nature be non-marginal. As a result, Central Asian governments will find it meaningful to embrace new modes of policy formation in order to address the challenges of environmental policy.

In order to understand the importance of distributive issues, answers to the following questions need to be provided. The first is who benefits and on whom the costs fall when environmental policies are implemented. Policy measures – by their very nature – create gainers and losers. Notions about the direction and volume of impacts are therefore required. The second is how the distribution of benefits and costs vary with the type of instrument employed in the implementation of the policy. A vast literature on instrument choice in environmental policy has identified the determinants of policy outcomes on individuals on the basis of income, endowments, and other characteristics. The third question is to what extent these distributive effects should guide the choice between different competing environmental policies and what concepts allow a link between policy objectives, distributive outcomes, and policy instruments. Answering this question is perhaps the most important step in the argument, as it is by no means a foregone conclusion that environmental policy should also contain explicit distributive objectives. If anything, there are sound theoretical reasons and an empirical record that suggests that it should not. This paper will try to argue, however, that there are important reasons for considering distributive impacts even under the narrow objective of overall efficiency of policies. The last question is how policy-makers can better integrate distributional concerns without compromising the policy's environmental goals.

The paper develops as follows: In the following section, I discuss various dimensions of distributive issues in environmental policy, with reference to selected environmental problems faced by Central Asian countries. This is followed by a consideration of arguments why these distributive issues should matter for policy-makers. It then points to possible avenues for addressing these distributive issues in the design of environmental policies and draws conclusions.

[1] For a full treatment of distributive issues in environmental policy-making in general, see Johnstone and Serret (2006); for a treatment focusing on conservation policies in particular, see Goeschl et al. (2008).

2. Dimensions of distributive impacts

Environmental policies create costs and benefits. These costs and benefits possess an explicit socioeconomic, spatial (geographical) and intertemporal (time) dimension. In socioeconomic terms, for example, only people deriving income from certain activities may be affected by the introduction of new policy measures. For instance, policies aimed at reducing the use of pesticides in the interest of groundwater protection may subject a farming population particularly reliant on their use to considerable harvest losses. Along the time dimension, the effects of a policy can be transitory, long-lasting (as in the case of stock pollutants), or even permanent (as in the case of extinction of a species). Environmental policies can thus affect future generations in a profound manner. Likewise, heterogeneity of conditions is likely to lead to very different sacrifices having to be incurred by different parts of a country in order to meet certain environmental targets and very different benefits accruing to local populations. Membership of a specific socioeconomic group, time, and space are therefore important facets of distributive impacts.

Spatial patterns are particularly important to the extent that a “spatial mismatch of costs and benefits” (Wells, 1992) exists in a peculiar environmental policy. Such a mismatch occurs when a high spatial diffusion of benefits coincides with a high local concentration of costs. Nature protection policies provide a typical example, but many of the classic policies having to do with fluvial water resources and harmful emissions fulfill the characteristics of a spatial mismatch. Alongside the presence of a ‘spatial mismatch’, there is an emerging fine structure to spatial impacts and evidence of the possibility of local reconciliation of costs and benefits that comes out of the growing set of local and regional level case studies.

The intergenerational distributive dimension of environmental policies is also significant. The reason is that policies have clear intertemporal impacts, affecting generations far into the future. Problems of intergenerational equity can be addressed, but a metric is needed for deciding between outcomes across different time periods. A key part of that metric will be the discount rate. An increasingly common procedure is to use a hyperbolic discounting (i.e. declining discount rate) of costs and benefits arising at different points in time. At the same time, consistency between inter- and intragenerational equity is required.

Assuming that environmental policies fulfill the minimum criterion of an *aggregate net gain*, this means that across all members of society the total gains from the policy outweigh the losses. Once this requirement is met, however, policies commonly place considerable burden on some groups within society to the benefit of other groups. The spatial and intertemporal distributive effects are therefore part and parcel of environmental policy making, in Central Asia and elsewhere.

3. Evidence of distributive impacts across socioeconomic groups

Assessing the impact environmental policies have on individual wellbeing is a challenging task for three reasons: First, public goods and services related to the environment will not be traded on markets either for consumption or as production inputs. The functional dependence of individuals and groups on environmental services is therefore frequently not easily evident prior to the policy intervention.

The second reason is that the value of these goods and services relative to other goods (the relative price) cannot be observed directly. Together this means that the contribution of environmental goods and services to welfare can only be fully assessed through procedures that impute their quantity and price indirectly. Here, the assessment builds on a number of empirical studies that provide guidance on the direction of the volume of welfare changes brought about by environmental policies.

The third reason is that the impact of environmental policies at the individual level is generated by an overlap of two quite different incidence patterns, one pattern depicting the incidence of benefits, the other the incidence of costs. Together, these determine the net benefits (gross benefits minus costs) arising at the individual level.

The following two sections summarize some general statements regarding the nature of these two patterns, starting with the incidence of gross benefits across socioeconomic groups.

3.1. EVIDENCE ON DISTRIBUTIVE PATTERNS OF BENEFITS FROM ENVIRONMENTAL POLICIES

Just like in the case of other goods and services, the demand for environmental goods and services exhibits income effects. These effects can be negative, as Russell and Vaughan (1982) demonstrate in a study on the relationship between income and the demand for recreational fishing. For most services, however, income effects are positive, which is consistent with the idea that environmental goods and services are normal goods.

Income effects for environmental policies are commonly reported as the income elasticity of willingness to pay for the environment, which – by convention – is the percentage change in willingness to pay for a one-percent change in income. Positive elasticities imply that the rich benefit more from environmental improvements than the poor. Income elasticities of more than one indicate that the environmental good is a ‘luxury’ good, as the willingness to pay for this good increases faster than the growth in income. For 'luxury goods', the distributive effects of public policies designed to increase their supply are strongly progressive, with the rich benefiting disproportionately out of the provision.

Theoretically, there are three reasons for predicting a positive and significant income elasticity of the willingness to pay for environmental goods and services.

1. Most environmental goods and services have all of the properties of 'normal' goods (Baumol and Oates, 1988).
2. Rising incomes do not only lead to a higher demand for each normal good, they also lead to a demand for more goods (Dixit and Stiglitz, 1977; Theil and Finke, 1983). The inherent variety of environmental goods and services should therefore elicit a higher willingness to pay (Bellon and Taylor, 1993).
3. Increasing scarcity of rare environmental resources may induce a change in preferences towards a higher marginal valuation. This is the argument made in the seminal paper by Krutilla (1967).

On this basis, we would expect an income elasticity of WTP for environmental goods and services close to one or above. Empirical estimates for environmental goods and services are not plentiful. There are also good theoretical and methodological reasons for taking these estimates with strong caution (Flores and Carson, 1997). Bagnoli et al. (2008) summarize the results of studies and meta-studies. Without going into the details of study methodologies and econometric considerations, estimates range between values of 0.2 up to 2. The mean income elasticity of willingness to pay for environmental policies lies somewhere in the region of 0.5. It is therefore positive, and it is possible that it is above 1 for a number of important cases. On the basis of the findings, there are strong theoretical and empirical reasons for predicting that the primary benefits of environmental policies will accrue to a greater extent to households with higher incomes.

3.2. EVIDENCE OF DISTRIBUTIVE PATTERNS OF THE COSTS OF ENVIRONMENTAL POLICIES

The costs of implementing environmental policies are the second key determinant of net benefits at the individual level. Assessing their incidence requires understanding the sacrifices required at the individual level for implementing environmental policies. The extent of these sacrifices is often an inherent feature of the policy in that it determines the share of the economic burden borne by society at large through general taxation and the share of the economic burden borne by specific groups. In a seminal study on protected areas, Dixon and Sherman (1990) categorize the costs of environmental policies the following way.

- Direct costs – these are the costs of implementing the policy, which involves budgetary expenses raised through taxation. These costs are borne by the general public and their socioeconomic incidence matches that of other public funds raised from the population.
- Indirect costs of the policy – these are non-budgetary, but material costs arising from the implementation of the policy. Typical examples are crop losses at the boundaries of protected areas as a result of increased wildlife population levels within or reductions in irrigation water available to farmers. These costs are borne by those specific groups that are materially connected with the results of the policy.
- Opportunity costs of the policy – these costs are the value of alternative uses foregone by virtue of implementing the policy. Opportunity costs arise through the immediate sacrifice of consumption possibilities previously exercised and no longer possible; and through the delayed sacrifice of potential future gains that would have arisen from alternative uses of the existing assets. This second component, however, varies strongly with the degree of irreversibility of the policy.

Clearly, the incidence of these costs will determine the impact of policies at the individual level and diminish the gross benefits, if any, delivered by the implementation of a particular policy. Together then, the patterns of gross benefits and costs jointly result in a specific change in the welfare position of individuals.

4. The role of distributive effects

Should these distributive effects matter for the design and implementation of environmental policies? There is a strong tradition in welfare economics that they should not. There, it is a key doctrine that policies aimed at correcting externalities (such as environmental policies) and policies aimed at redistributive objectives should be separated. The intuition behind splitting these two objectives into separate policies rather than pursuing them in an integrated fashion is simple: Separating equity and efficiency objectives leaves environmental policies unencumbered by additional constraints and obligations and free to pursue those policy options that promise to deliver the greatest social gains. These maximized social gains generated by environmental policies are then available for redistribution. This means in simplified terms that policy choice should come down to ranking policies according to their contribution to social welfare (based on an exhaustive analysis using cost-benefit analysis), choosing the highest ranked policy that is feasible, and implementing it.

However, separation of efficiency and distributive effects rests on the condition of separability. In the context of environmental policies, there are a number of fundamental and practical reasons why the conditions of separability may frequently not be met. In these cases, pursuing policies without regard for their distributive consequences may involve serious efficiency losses. The reasons for concerns over separability fall into two categories. The first includes limitations that ultimately have to do with the nature of the environment as an economic good that has strong public goods aspects, with the informational imperfections inherent in environmental policies, and in the presence of transactions costs in carrying out ex post redistributive transfers. Serret and Johnstone (2006) and Bagnoli et al. (2008) discuss these issues in detail.

The second category has to do with practical limitations to separability, i.e. the presence of real world obstacles to implementing the redistributive part of the separable policy. These obstacles are the products of a number of factors and are covered in great detail in Serret and Johnstone (2006) and Bagnoli et al. (2008). Only two of the most important ones are pointed out here: The problem of intervening through environmental policy in management systems that manage a resource as common property, such as many irrigation systems around the world; and the problem of environmental policy interventions leading to conflict among those affected by the policy.

4.1. COMMON-PROPERTY RESOURCE SYSTEMS

Many environmentally relevant resources, such as irrigation water or forest areas, are frequently managed in the context of institutions and practices of common property resource (CPR) management. In such settings, both the degree of efficiency of aggregate resource management decisions and the institutions that coordinate individual management decisions are to significant degree endogenous to the distribution of income and wealth among those participating in the management. In such settings, equity and efficiency are inseparable, and outside interventions that induce changes in the distributional patterns can lead to unpredictable changes in resource management.

Both the theoretical and empirical literature on CPR stress the causal links between efficiency (in terms of successful management) and distribution. While starting from a theoretical result stating the exact opposite, i.e. that distribution of income and contributions to a public good, can be separated (Warr, 1983), subsequent qualifications have emphasized that in general the two issues are inherently linked.

The management of common property resources can be framed as private provision of a public good. The public good under consideration in CPR is resource conservation. Inferior management of an open access resource due to the absence of hierarchically superior institutions is called the 'tragedy of the commons' (Hardin, 1968). Consumption of the common resource by one agent restricts access by other users. Insofar as these negative externalities are not taken into account, the resource is overused and the allocation inefficient. Warr (1983) pointed out that in a public good game, the size of the inefficiency is independent of the distribution of income among users. This is the basic claim for separability of efficiency and distribution in CPR. Bergstrom et al. (1986) on the one hand confirm the separability for small changes in the distribution of income but on the other hand present the first limitation. If redistribution changes the number or identity of users, aggregate resource consumption and hence efficiency are affected.

Both Warr (1983) and Bergstrom et al. (1986) derive their results in stylized settings with a pure public good and a convex provision technology. All users are therefore equally affected by excessive resource use and conservation of the resource does not require any fixed upfront investments such as a switch of technology or institutional setting. However, both conditions are hardly ever met in reality. Baland and Platteau (1997) show that if these conditions do not hold, an increase in inequality among the potential users of the resource can have significant effects on efficiency. A small redistribution from rich to poor can induce a collapse of conservation efforts. Taking income or access rights from the better off can reduce their willingness to contribute to conservation in a way that cannot be compensated for by the increase in the willingness to contribute by the poor who gain from redistribution. This is due to a co-ordination problem that arises when the provision of the public good involves non-convexities (e.g. fixed costs). Unless large contributions by the rich pass a certain threshold, contributions from all users collapse. Hence, a narrow focus on the poorest users of a CPR can result in disastrous conservation policies.

Another channel through which inequality can influence efficiency arises if users can invest in extraction capacity. Aggarwal and Narayan (2004) find that users invest in excess capacity except when inequality is very high. The resulting relation between inequality and efficiency is non-monotonic. In these cases efficiency of resource use is highest when inequality is either very low or very high.

The initial distribution of wealth, skills and access rights does also affect the performance of a policy imposed by a superior authority on a commonly managed resource. Baland and Platteau (1998) find that such interventions tend to increase inequality among users. Poor agents are therefore more likely to be hurt by such measures. Moreover, if a policy is required to benefit all users, i.e. to be Pareto superior to the original state of the world, its efficiency gains are decreasing in the inequality of users. This holds for commonly used instruments such as uniform quotas and taxes.

The empirical evidence on the performance of CPR management is mixed. While the 'tragedy of the commons' certainly is a real world phenomena, it does not imply that all commons are managed badly by their local community of users (Ostrom and Gardner, 1993; Hegan et al., 2003). However, successful schemes tend to collapse when rapid changes in the population of users, technology, and economic and social conditions occur (Dietz et al., 2003).

Recent empirical evidence affecting environmental and distributive impact of regulatory schemes in CPRs are summarized in Bagnoli et al. (2008). Only one study finds a progressive impact of the conservation policy. Hence, there is strong support that conservationist interventions tend to favor the already better off users of a CPR.

To sum up, equity and efficiency are inherently linked in the management of CPRs. Save for some very specific cases, the distribution of access rights, income and access to alternative sources of income have direct and significant effects on efficiency. Moreover, attempts to intervene into such schemes cannot untie this link. Their effect on both efficiency and equity are subject to the initial distribution.

The important contribution of unambiguous and enforceable property rights to preventing conflicts is re-emphasized with a different twist in a study by Burton (2004). Here the link between the effectiveness of a policy and its distributional consequences arises through an explicit modeling of formal and de facto property rights. Burton shows that conflicts over policies that restrict access to previous users will take on the character of a "war of attrition" in which the holder of formal property rights can lose to local residents willing to invest in de facto property rights (e.g. by blocking access). The reason is that by imposing a sufficiently high negative distributive impact, policy-makers make it worthwhile to those affected to invest considerable resources in a conflict, in particular in the absence of alternative options. The formal quality of property rights is therefore less important for the probability of conflict than the credibility of their enforcement.

4.2. CONFLICTS

The fact that environmental policy interventions often create conflicts in the course of their implementation is the second reason for questioning the wisdom of removing redistributive concerns from environmental policies. Policy-induced conflict is typically associated with policies involving strong redistributive effects, particularly at the expense of a well defined group of individuals. These have the capacity to mobilize policy losers with a view to undermining the implementation of the policy, the subsequent management regime, or both. This raises the cost of policy implementation and can make the pursuit of the original policy thoroughly unattractive on efficiency grounds alone (Bardhan, 1996). These costs arise in two forms: One is that policy implementation has to be accompanied by visible and credible enforcement activities. These activities are costly. Second, if parties find it worthwhile to challenge the policy through open conflict, then these costs subtract from the net gain generated by the policy implemented. The possibility of distribution-induced conflict alone is therefore relevant for policy choice.

4.2.1. *Enforcement activities*

Enforcement activities are costly, but necessary for policies likely to induce conflict. This introduces a trade-off between effectiveness of the policy and the need for an enforcement budget.

Albers and Grinspoon (1997) offer a comparative study of two monitoring and enforcement regimes. Clear trade-offs are identified. Increasing the budget for enforcement allows both for a larger area to be monitored and for an increased reliance on ‘police and punish’ approaches to enforcement, as for example in the Khao Yai National Park in central Thailand. In contrast to the more inclusive and less well funded approaches employed in the Xishuangbanna Nature Reserve in southwestern China, these approaches are effective in deterring some of the encroachment, but also induce local people to undertake socially costly avoidance activities. Higher monitoring and enforcement intensity in the case of the Khao Yai National Park does not result in uniformly superior conservation outcomes, however: While the core areas of the National Park are better protected against resource extraction and agricultural encroachment, these activities are pushed to the peripheral areas within the National Park where the risk of detection and punishment is lower. By contrast, the negotiated approach in the Xishuangbanna Nature Reserve results in average conservation achievements, which are lower, but there is greater ability to influence the spatial patterns of activities (Albers and Grinspoon, 1997).

These findings mirror a general conclusion of the literature on conflicts surrounding protected areas, namely that effective policing of protected areas involves considerable costs and an ongoing funding commitment that need to be considered within the planning process (Neumann, 2004; Peluso, 1993).

4.2.2. *Costs of conflict*

There is increasing evidence that conflicts over natural resources can have significant costs that are relevant even at the macroeconomic level (Sachs and Warner, 1997; Bannon and Collier, 2003). This is particularly the case when the resources concerned are spatially concentrated, as is characteristic for environmental policies with their spatially explicit targets of ecosystems and habitats (Bulte et al., 2005).

The economic literature provides two lenses through which to view the problem of conflict. One are rent-seeking models, where the size of the rent to be captured and the cost of acquiring this rent are usually fixed; the other are conflict models, where the size of the rent and the opportunity cost of capturing it are endogenously determined with the ‘game’ (Wick and Bulte, 2006). Both lead to the conclusion that conflict is welfare-decreasing since it is unproductive, but differ in the scale of welfare losses to be expected (Neary, 1999). Their general message is twofold:

- Policy-makers need to foresee policy-induced conflicts and factor their expected cost into the evaluation of the respective policies prior to ranking them for efficiency purposes.
- Policy-makers need to recognize that conflicts have spill-overs beyond the specific policy under debate. This is because conflicts destroy the social capital on which existing and future institutions rely (Pretty, 2003).

In the context of environmental policies, conflicts have been analyzed theoretically and empirically with a special emphasis on the forest conservation context. In a well-known study, Alston et al. (1999) examine conflicts and violence in the wake of land reform in Brazil. There, insecurity of property rights is conducive to conflict, since investment of resources in a contest over land becomes more profitable as the probability that the land will fall to the contesting party increases. This points to the importance of the definition and enforceability of property rights as a key determinant of conflict probability that is mirrored in other studies: Haro et al., 2005 consider the problems of ambiguity in property rights definitions in the case of grazing management in northern Kenya; Fearnside (2003) analyzes the proliferation of different property-rights regimes as a result of horizontal (different groups) and vertical (different level of political hierarchy) conflicts.

4.3. SUMMARY

Environmental policies involve the creation of winners and losers. When distributive effects of environmental policies are non-marginal and redistributive policies cannot be relied upon to re-establish a desirable distribution of income and wealth ex post (as presumably in the status quo ex ante), then environmental policies have to assume more of the weight of integrating equity concerns into the policy itself.

There is an extensive literature showing that distributive issues become salient for environmental policy-making in a variety of ways. This literature demonstrates the importance of the institutional setting for accommodating losers from policies. Where channels for protest are available and can be accessed at reasonable cost, institutions charged with solving distributional conflicts can carry out their work without further delay and without incurring additional cost. Where such channels are not available, distributive issues spill over into other arenas and can be contained only at significant expense in terms of time and resources. Even when the initial resolution of distributive issues is broadly successful, however, there are important intertemporal effects that can threaten or undo the original policy. Policy-makers are therefore increasingly expected to consider the distributive impacts of their policies and to design mechanisms for successfully addressing distributive issues that become policy-relevant while ensuring that the objectives of the policy will be fulfilled.

5. Relevance to Central Asian countries

What is the relevance of these considerations for Central Asian countries? While case studies on distributive issues in environmental policy-making in Central Asia are few and far between, the countries of this region stand out for the scale of environmental problems they will have to confront in the short to medium term. Many of these problems are covered in detail elsewhere in this volume, ranging from issues of water quantity and quality to air pollution, biodiversity loss, and climate change. These are likely to cause welfare impacts that are much larger relative to GDP than in industrialized countries. Given the scale of these impacts, the policies intended to address these problems will by their very nature have to be non-marginal. Given the importance of agriculture and base industries in these countries, environmental policies will also directly interfere with the livelihoods of many of their citizens. Many of the concerns that make distributive issues relevant are therefore present.

Three implications result from the considerations regarding the distributional impact of environmental policies in Central Asia. The first one is that countries in Central Asia will find that policy templates developed by regulatory leaders, such as the OECD countries, are less useful for developing domestic policy frameworks than previously thought. The reasons are, first, that policy interventions in the OECD rely on institutional structures specific to highly developed and highly industrialized countries with significant experience in channeling public preferences into policies. Developing countries are generally characterized by institutions with restricted budgets and limited access to policy-making expertise. The second reason is that even regulatory leaders such as OECD countries have not experienced unqualified successes with the policies implemented in their own countries. This limits the attractiveness of using policies of OECD countries as templates for other countries. The final reason is that due to the delay in implementing policies, countries in Central Asia have to contemplate policies on a very different scale in order to address the environmental policy challenges in their countries.

The second implication of the above considerations for countries in Central Asia is that the degree of policy complexity in the environmental domain is considerably more complex in these countries. This is for the simple reasons that while environmental policies in most developed countries address problems where governments provide solutions to issues of market failure, many of the root causes of environmental problems in Central Asian countries have to do with government failure. This means that government itself frequently features as part of the problem rather than as a means to a solution. Obviously, in such circumstances, it is reasonable to expect much less from government intervention in such a setting.

The third implication is that given the need for non-marginal changes, distributional issues of environmental policies are more salient for countries in Central Asia than elsewhere. The reason is that non-marginal changes brought about by environmental policies typically lead to more substantial distributive effects among the population concerned. With distributive issues looming large, policy-makers typically find the range of desirable policies to choose from severely restricted compared to situations in which such issues do not arise.

6. Conclusions

This paper has addressed the importance of distributive issues for environmental policy-making in Central Asian countries. Environmental problems in Central Asian countries are severe and require non-marginal policy interventions. Distributional effects impact various dimensions against which policy interventions are evaluated. One dimension is the welfare gains expected as a result of the policy. To the extent that welfare gains accruing to individuals of different income or wealth are evaluated differently, different distributive patterns will lead to different measures of welfare gains, even if the aggregate welfare gains from different policies are the same in raw dollar terms. Since there are sound economic reasons for introducing such a distributive weighing of welfare impacts, governments may find it worthwhile to consider alternative policies from those pursued in the past.

A second dimension along which policies may be evaluated is the feasibility of a policy intervention. To the extent that distributive effects influence the amount of resistance or protest from local populations vis-à-vis a policy, policies that are skewed against the interests of groups able to mobilize important impediments to policy implementation should be re-evaluated in the light of broader notions of policy efficiency.

At the same time, non-marginality of interventions leads to significant negative economic impacts on well-defined groups of people within Central Asian societies. The paper argues that distributive issues merit consideration in the process of policy-making. Implementing policies that neglect those negatively affected by it can lead to outcomes that are ultimately undesirable from a social perspective. Distributive issues therefore impose additional constraints and are likely to be salient features in Central Asian policy-making over the short to medium term.

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GOVERNING OF ENVIRONMENTAL PROBLEMS AND IMPACTS IN BULGARIAN AGRICULTURE – LESSONS FOR CENTRAL ASIAN COUNTRIES

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Abstract. This paper presents lessons from environmental management in Bulgarian agriculture for Central Asian countries. Comparative institutional analysis is employed to evaluate the potential of diverse governing modes to deal with environmental problems and risks, protect absolute and contracted eco-rights, stimulate eco-investment, and intensify and coordinate eco-activities. Firstly, we assess market efficiency, private and public modes in Bulgarian agriculture, and the identity of major environmental challenges. Next we withdraw conclusions about how positive and negative experiences from the Bulgarian transition could be used to modernize environmental management in Central Asia. The post-communist transformation of Bulgarian agriculture has been associated with a relaxation of general environmental pressure, but also has brought about significant new problems, such as degradation and contamination of farmland, pollution of surface and ground waters, loss of biodiversity, etc. Central Asian countries should adapt the Bulgarian experience to their specific economic, institutional and natural environment. More particularly, there is a need to modernize institutional structures by introducing new eco-rights, redistributing rights to natural resources, liberalizing eco-activities, and improving systems of enforcement of eco-rights. Next, it is necessary to apply a collaborative, multi-disciplinary approach in governing public support, research, education and extension programs embracing economic, social, environmental, and other aspects of agrarian sustainability. It is also important to select more effective modes for public intervention (regulation, assistance, financing, and partnership with the private sector) and enhance direct public involvement in environmental preservation and improvement. Furthermore, different forms of public and

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international assistance should incorporate environmental measures in the dominant modes of farming governance in each country; take into consideration all advantages, disadvantages and impacts of individual forms; commit to and effectively fund achievement of long-term goals; secure equal access of all types of farms to support programs; and involve farmers and other stakeholders in program management and implementation.

Keywords: Environmental management, governing modes, agrarian sustainability, Bulgarian transition, Central Asia, New Institutional Economics

1. Introduction

Bulgaria is a small country in South-Eastern Europe which has gone through a fundamental transition from a communist to a modern market economy. Harmonization with EU institutions has been successfully completed and the country joined the Union on January 1, 2007. Transformation of agriculture has been associated with significant changes in farming structures and environmental impact of the sector (Bachev, 2007b).

Most Central Asian countries have been experiencing environmental challenges similar to those of Bulgaria due to their comparable geographic latitude, natural resources, and historical experiences with public farming systems, over-intensive farming, and painful economic and socio-political transformation. Therefore, lessons from positive (and negative) Bulgarian experiences in governing environmental challenges could be very important for that region.

Environmental management is an essential aspect of sustainable agrarian development. It is increasingly a hot topic of interest to policy makers, academicians, agrarian and rural agents, the business community, interests groups, and end consumers. There have been a number of studies on specific environmental problems in transitional countries from Central and Eastern Europe (Bentcheva and Georgiev, 1999; Gatzweiler and Hagedorn, 2003; Sumelius, 2000). However, there are no publications on how experiences from the Eastern European transition could be used effectively in Central Asia.

In this paper, we try to apply lessons from governing environmental problems and impacts in Bulgarian agriculture to Central Asian countries. We incorporate an interdisciplinary methodology of the New Institutional and Transaction Costs Economics based on the contributions of Coase (1960), Furuboth and Richter (1998), North (1990), and Williamson (1996). Comparative institutional analysis is employed to evaluate the potential of diverse governing approaches to deal with environmental problems and risks, protect absolute and contracted eco-rights, stimulate eco-investment, intensify and coordinate eco-activities, etc. First, we assess the efficiency of the market, as well as private and public modes for environmental governance in Bulgarian agriculture, and identify major environmental problems and risks. Secondly, we summarize lessons from the Bulgarian transition for further modernization of environmental management in Central Asia.

2. Modes and efficiency of environmental management in Bulgarian agriculture

2.1. INSTITUTIONAL ENVIRONMENT

Since 1989, Bulgarian agriculture has seen a fundamental transformation of property rights and institutional structures (Bachev, 2006). New private rights to major natural resources have been introduced or restored, markets and trade have been liberalized, and modern forms of public intervention have been put in place.

During most of the transition, diverse environmental rights (to clean and beautiful nature; preservation of natural resources, and biodiversity) were undefined or poorly defined and enforced (Bachev, 2007b). An out-dated system of public regulations and control, which corresponded little to contemporary needs of environmental management, dominated until recently. Moreover, there was no modern system for monitoring the state of soil, water, and air quality, and a lack of credible information on the extent of environmental pollution and degradation. Furthermore, there existed neither social awareness of the "concept" of sustainable development nor any "need" to be included in public policy and/or private and community agenda.

In the last few years, the country's laws and standards were harmonized with the immense EU acquis for environmental governance. In fact, the entire concept of sustainable development incorporating environmental, rural development, and other issues has been brought to the public agenda from outside (EU demand, pressure, and policies). The latter contributed significantly to the speed of institutional modernization and building a modern framework for environmental management in the country.

However, a good part of the new "rules of the game" are not well-known or understood by the various public authorities, private organizations and individuals affected. Even now there is not enough readiness for effective implementation of the new public order because of the lack of experience in agents and adequate administrative capacity. In many instances, the enforcement of environmental standards is difficult, since the costs of finding and penalizing of offenders are very high. Moreover, it has been impossible (due to high costs and lack of political will) to enforce novel quality, eco-, animal welfare etc. norms in the huge, informal sector of the farming economy.

As a further complication, the harmonization with the EU legislation and the emergence of environmental organizations started to generate new conflicts between private, collective, and public interests. As a result, public choices have not always favored effective environmental management (Bachev, 2007b).

What is more, a multifunctional role of farming has not been effectively recognized; a proper system for its assessment has not been introduced; and there is no provision of a public service "environmental preservation and improvement" funded by society. Essential public institutions and infrastructure crucial for the sustainable farming development have not been built (Bachev, 2006). For instance, the newly established agricultural advisory system does not serve the majority of farms or include environmental management issues.

2.2. PRIVATE AND MARKET MODES

During much of the transition of the newly evolving market, private and hybrid structures were not efficient in dealing with various environmental issues.

Privatization of agricultural assets and restructuring of public farms took almost 10 years to complete. During a good part of that period, critical agrarian resources were governed by ineffective provisional structures such as Privatization Boards, Liquidation Councils, Land Commissions, etc. This poor governance was combined with high economic uncertainty and interdependency of many agrarian assets (Bachev, 2006). Consequently, most farming activities were carried out in inefficient and unsustainable structures, such as part-time and subsistence farms, production cooperatives, and huge business farms based on provisional lease-in contracts (Table 1). Even now 97% of the livestock holdings are "unprofessional farms" with only a few head, but these farms breed 96% of the goats, 86% of the sheep, 78% of the cattle, and 60% of the pigs in the country.

Dominant farming structures have had few incentives to make long-term investments to enhance environmental performance (Bachev, 2007b). The cooperative's large membership makes individual and collective control over management very difficult, focuses efforts on current indicators, and gives great possibility for mismanagement. Besides, given the small shareholding, advanced age, and non-employee status of most members, the incentives for long-term investment in land improvement and renovation of assets have

TABLE 1. Evolution of farming structures in Bulgaria.

Type of farm	1985	1995	2005
Public farms	298		
Share of total number (%)	0.02		
Share of farmland (%)	86.1		
Average size (ha)	12,600		
Unregistered	1600,000	1775,000	515,300
Share of total number (%)	99.9	99.7	99
Share of farmland (%)	13.9	46.5	33.4
Average size (ha)	0.38	1.35	1.8
Cooperatives		2,623	1,525
Share of total number (%)		0.1	0.3
Share of farmland (%)		40.7	32
Average size (ha)		800	584
Firms		2,200	3,704
Share of total number (%)		0.1	0.7
Share of farmland (%)		12.8	34.6
Average size (ha)		300	259.4

Source: National Statistical Institute

been very low. On the other hand, small-scale and subsistence farms possess insignificant internal capacity for investment, and little potential to exploit economies of scale and scope. They have few incentives to support initiatives that do not contribute directly to productivity and profit, such as preservation of biodiversity and the environment. Likewise, the larger business farms operate mainly on leased land and therefore concentrate on quick returns on investment. That lack of intrinsic motivation is coupled with ineffective enforcement of official standards for ecology, land use, biodiversity, etc.

Furthermore, during the entire transition the agrarian long-term credit market was practically blocked (Bachev, 2005). In addition, newly evolving farming has garnered little support in Europe (OECD, 2000). Until recently public aid was available mainly in the form of preferential short-term credit for the grain producers and minor support for capital investments. That policy additionally contributed to the destructive impact of unbalanced N fertilization by the biggest producers having access to the programs.

Only a small proportion of the farms have benefited from increased public assistance in recent years, most of them large enterprises (Bachev, 2005). Basically, a publicly supported farm must meet the requirements for good environmental performance. However, uneven and meager support for farms, the absence of clear criteria for eco-performance and effective control, and the delay in implementing "Agro-ecology" measures have contributed little to overall improvement of the environmental situation in the country.

Hence, since 1990 all "environmental management" has been left on farmers' "good will" and "market signals". Market governance has led to a significant decline in major crop and livestock production (Figure 1). That has been due to the multiple interrelations between rise in agrarian inputs and farm produce prices, drop in internal and export demands, and failure of a great number of farms to adapt to the new market environment.

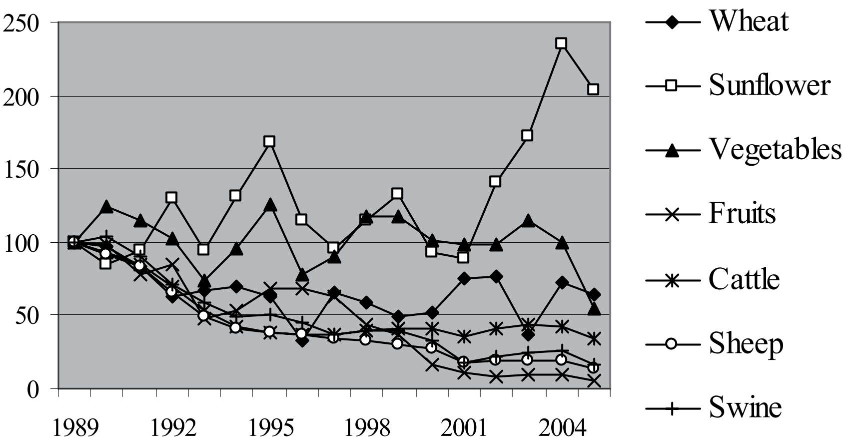

Figure 1. Dynamics of major crop and livestock production in Bulgaria. (National Statistical Institute.)

The smaller size and owner-operated nature of the majority of farms allowed them to avoid certain problems caused by large public enterprises in the past (e.g. lost natural landscape, biodiversity, nitrate and pesticide contamination, massive manure concentration, and uncontrolled erosion). It has also revived some traditional (and more sustainable) technologies, varieties and products. Side effects of that "market and private governance" were de-intensification of agriculture and a reduction of general environmental pressures compared to pre-reform levels (Bachev, 2007b). Consequently, a good part of the farm production was "organic" in character, obtaining a good reputation for products with high quality and safety. The private mode has also introduced incentives for the adoption of integral environmental management measures (including revival of eco- and cultural heritage, anti-pollution, aesthetics, comfort, etc.) These smaller farms have profited from the development of inter-dependent farming, agro-tourism, processing, trade etc. However, private management often has been associated with less concern for manure and garbage management, over-exploitation of leased and common resources, and contamination of the air and groundwater.

Market driven organic farming has emerged in recent years as well (Figure 2). It is the fastest growing farming sector, but still accounts for less than 1% of farmland, livestock and farm output. The National Action Plan for Developing Organic Agriculture provides significant public support for conversion and envisages 8% of the farmland to be managed under organic methods by 2013 (MAF, 2005). The organic farm was introduced by business entrepreneurs who managed to organize, fund and export products of this new venture. Eco-labeling of processed farm products has also appeared. In general, consumer confidence in certification and labeling is low, which impedes the evolution of internal markets for organic and eco-products (Bachev, 2007b).

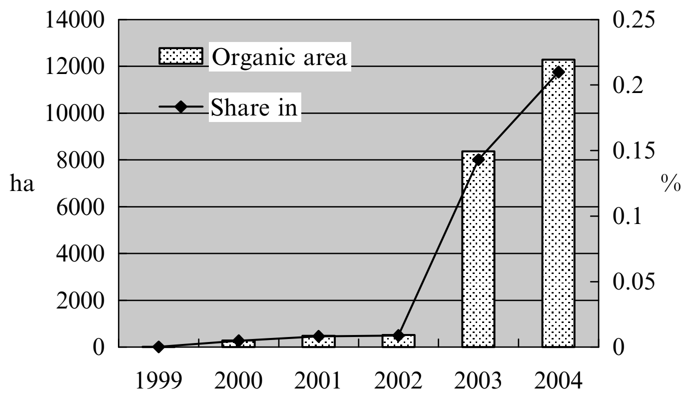

Figure 2. Development of organic farming in Bulgaria. (Ministry of Agriculture and Forestry.)

Starting in 2001 the assets of publicly owned irrigation companies were transferred to newly evolving Water Users Associations. However, the expected "boom" in efficiency from collective management has not materialized. This is due to the (semi)monopoly situation of regional water suppliers, few incentives for water users to renovate facilities and expand irrigation, and incomplete privatization of state irrigation assets.

Finally, the evolution of farmers and environmental associations has been hampered by the large number of rural agents and their diversified interests (size of ownership and operation, type of farming, individual preferences, different age and horizon, etc.). Despite the fact that the importance of such collective modes is growing, they are still insignificant.

2.3. PUBLIC MODES

In the last several years, a number of public programs have been developed to deal with the emerging environmental challenges, such as eco and biodiversity preservation, proper water management, and greenhouse gas emission limitation. National monitoring systems for environment and biodiversity have been set up and a mandatory ecological assessment of programs was introduced. Nevertheless, public involvement has been insignificant, fragmented and reactive to urgent environmental problems (such as natural disasters). The programs are developed and executed in a highly centralized manner without involvement of independent experts and stakeholders. In addition, there is considerable deficiency in administrative capacity in terms of staffing, qualifications, and material and financial means. As a result, there is inefficiency in priority setting and implementation, and the public programs typically have very little impact.

A great number of international assistance projects (funded by the UN EU, World Bank, Foreign Governments, and NGOs) have been carried out to "fill the gap" of government failures. They try to introduce western experiences with sustainable development and make a difference. However, they are limited in scale and unsustainable over time; often not adapted to the local institutional environment; and above all unable to effect significant impact. The assessment of the likely impact of EU CAP implementation in Bulgarian conditions also indicates that it will have a modest environmental effect, and economic, social and ecological discrepancies among different farms, sub-sectors and regions will broaden (Bachev, 2007b).

2.4. ENVIRONMENTAL PROBLEMS AND RISKS

The total amount of chemicals used in post-communist agriculture has declined considerably as a result of reduced production and application of fertilizers and pesticides (Figure 3). This trend diminished drastically the risk of chemical contamination of farm produce and the environment. However, the use of fertilizers has diminished to the extent that nutrient stores are being depleted. An average of 23595.4 t N, 61033.3 t P_2O_5 and 184392 t K_2O have been irreversibly removed annually from soils since 1990. Furthermore, an imbalance of nutrient components dominates with the application of 5.3 times less phosphorus and 6.7 times less potassium than the appropriate rate for the nitrogen used. Moreover, a monoculture or simple rotation has been constantly practiced by most farms concentrating on a few profitable crops. All these practices further contribute to the deterioration of soil quality and organic matter content.

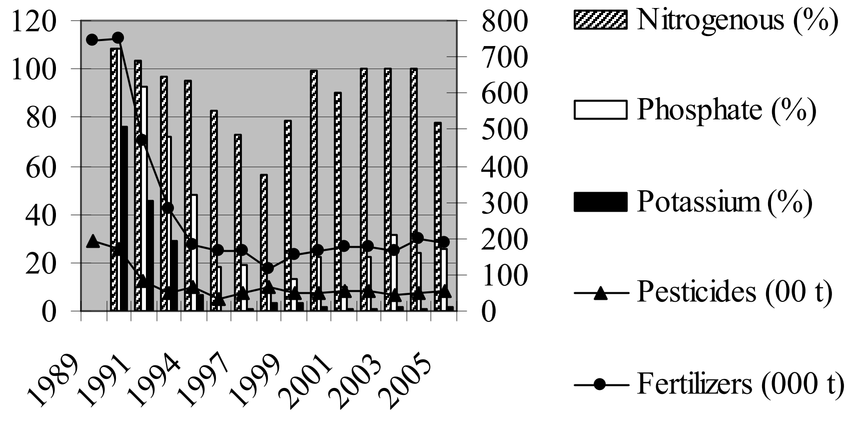

Figure 3. Rate of chemical application and fertilizer compensation in Bulgarian agriculture. (Ministry of Agriculture and Forestry.)

There has been a considerable increase in agricultural land affected by acidification (Figure 4) as a result of a long-term application of specified nitrate fertilizers and unbalanced fertilizer application. After 1994 the percentage of acidified soil decreased, but in recent years there has been a reverse tendency along with the gradual augmentation of nitrate use. The fraction of salinized land doubled after 1989 but it is still an insignificant part of the total farmland. During the entire period no effective measures have been taken to normalize soil acidity and salinity.

Erosion has been a major factor contributing to land degradation in the country (Figure 4). The progressing level of erosion is a result of extreme weather, but it also has been adversely affected by dominant agro-techniques, deficiency of anti-erosion measures, and uncontrolled deforestation. Around one-third of the arable lands are subjected to wind erosion and 70% to water erosion. Since 1990, erosion has affected between 25–65% of farmland and total losses varied from 0.2 to 40 t/ha in different years (EEA).

The impact of irrigation on erosion and salinization diminished significantly after 1990. There was a sharp reduction in irrigated farmland, as merely 2–5% of the existing irrigation network has been put to use. Moreover, a considerable physical distortion of irrigation facilities (including 80% of

Figure 4. Share of degraded agricultural lands in Bulgaria. (Executive Environment Agency.)

the internal canals) has taken place as a result of restructuring of farms and lower incentives for irrigation. The decline in irrigation has had a direct harmful effect on crop yields and the structure of rotation. In addition, irrigation has not been effectively used to counterbalance the effect of global warming on farming and further degradation of agricultural land.

The nitrate content in ground water has been decreasing, and now only 0.7% of samples exceed the ecological limit value (EEA, 2006). Nevertheless, monitoring of water for irrigation shows that in 45% of water samples, nitrate concentrations exceed the contamination limit value by 2- to 20-fold (MAF, 2006). Nitrates are also the most common pollutants in underground water, and for the last 5 years N levels have only slightly exceeded the ecological limit (EEA, 2006). Nitrate Vulnerable Zones cover 60% of the territory of the country and less than 7% of utilized agricultural land. The lack of effective manure storage capacity and sewer systems in the majority of farms contributes significantly to the persistence of the problem. According to the last census, only 0.1% of the livestock farms possess safe manure-pile sites, around 81% of them use primitive dunghills, and as many as 116,000 holdings have no facilities at all (MAF, 2003).

A serious environmental challenge has been posed by the inadequate storage and disposal of the expired/prohibited pesticides from the liquidated public farms. There are 477 abandoned storehouses registered for 11,079 t of pesticides, and 82% of all polluted localities in the country are associated with these dangerous chemicals (EEA, 2006). Beyond that, the number of illegal garbage dumps in rural areas have noticeably increased reaching 4,000 (EEA). Farms contribute extensively to the production of both organic and industrial waste materials.

Agriculture has caused significant degradation of biodiversity as a result of intensification and introduction of foreign plant varieties and animal breeds during the communist period, as well as a lack of any policy concerning protection of biodiversity afterwards. According to official data, all 37 native animal breeds in Bulgaria have been endangered during the last several decades (MEW, 2006). Since 1990, a considerable portion of agricultural lands have been left uncultivated for a long period of time, which caused uncontrolled development of some species and suppressed others. In addition many permanent natural and semi-natural grasslands have been severely damaged by under- or over-grazing. Reckless collection of certain wild plants and animals has led to destruction of natural habitats. Some genetically modified crops have been introduced without an independent assessment of possible hazards for farming and human health, or establishment of appropriate safeguards.

Finally, there has been a significant reduction in overall green-house gas emissions in general and emissions from agriculture in particular since 1988 (Figure 5). Agriculture has been a major contributor comprising 57% of to N2O emissions and a quarter of methane emissions. However, since 2000 farming related GHG emissions have begun to rise again slowly.

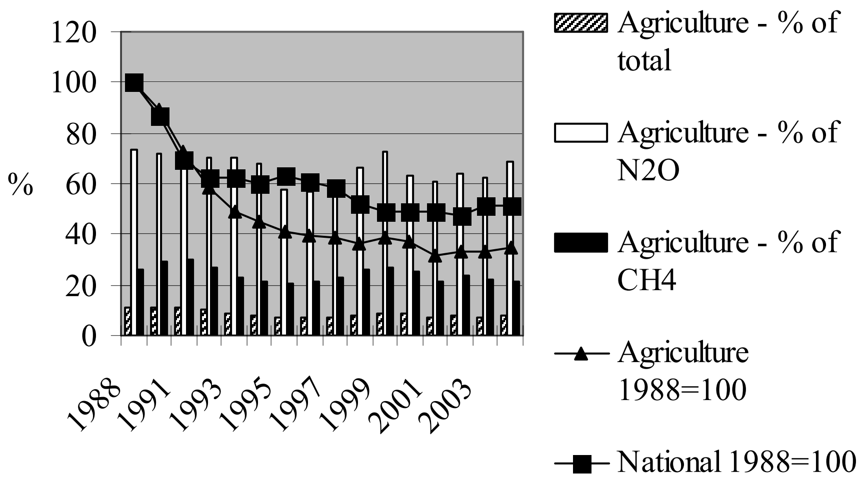

Figure 5. Trend and components of green-house gas emissions from Bulgarian agriculture. (Vassilev et al., 2006.)

3. Lessons from the Bulgarian transition

3.1. MODERNIZATION OF INSTITUTIONAL AND PROPERTY RIGHTS

The institutional environment is a crucial factor which eventually determines the type of agrarian development and the efficiency of environmental management (Bachev, 2007a). Therefore, universal goals of sustainable development have to be effectively put on the public agenda in all Central Asian countries. In that respect adapting positive experiences from other transitional and developed countries could play a critical role. What is more, an effective international pressure may accelerate the modernization of institutional and property rights in places where no emerging needs exist or there are no social mechanisms to bring about adequate change.

As in Bulgaria, environmental rights in many Central Asian countries are not well defined and/or properly enforced. The "right to contaminate" soil, water, air, and farm produce are considered natural rights of farmers and other producers. In many instances, the eco-rights of individuals and consumers are declared without the controls of official rights effectively enforced by authorities. Therefore, new rights to a clean environment, biodiversity, intellectual agrarian property and origins must be introduced while rights to natural and biological resources are redistributed (e.g. privatized). For example, establishment and enforcement of rights to protected agrarian products (such as "Protected Designation of Origin", "Protected Geographical Indication", and "Traditional Specialty Guaranteed" in EU) could contribute to the revival and preservation of traditional and more sustainable production methods, product varieties, technologies, and lifestyles in Central Asia.

Farmers have to be given rights to invest in and profit from environmental preservation and improvement. That would advance organic and eco-production and services. For instance, production of solar, wind, and methane energy on farms could be boosted in Central Asia if rights to generate and sell the energy are established. Furthermore, in order to protect valuable eco-systems and national parks from being overtaken by private and/or interest groups, special institutional arrangements have to be put in place in order to define protected areas, plants, and wildlife, as well as modes of their exploration and preservation. Furthermore, individuals and their organizations should be encouraged to protect and extend their eco-rights. This would increase efficiency of individual, community and public actions on environmental preservation and improvement.

Further liberalization of markets and private initiatives is also needed for effective environmental management. In Bulgaria there is a great possibility to profit from the production and export of organic products due to bigger comparative advantages in terms of costs, eco-conditions, and traditions. For a number of Central Asian countries, comparable potential exists for organic cotton production. However, that huge potential can hardly be explored without giving access to foreign certification bodies to operate (certify, control, and dispute rights) within the region. Freedom should also be granted to private agents to trade organic and eco products for their mutual benefit.

Next, widespread (quasi)monopolies in natural resources have to be dismantled and distortion of efficiency in using critical inputs (such as water) neutralized. The Bulgarian experience shows that it could be best accomplished through assignment of management (ownership) rights to user-farmers. Furthermore, in order to avoid unilateral dependency, farmers' rights are to be extended to water distributing companies as user participation in governing bodies guarantees. In such a way, existing problems in planning, allocation, dispute resolution, and under-investment associated with the scarce water resources in the region could be effectively solved. Similarly, privatization of all elements in the food chain and liberalization of trade could resolve reported "coordination and incentive problems" in the cotton chain in Uzbekistan.

Liberalizing markets and private entrepreneurship would allow dominating family farms, cooperatives, and agro-firms to explore their potential for growth in productivity and eco-performance. Moreover, it would let market and private agents develop new ventures for effective environmental management tailored to their specific needs.

3.2. INTEGRAL GOVERNANCE OF SUSTAINABILITY

It is still common to consider environmental management as something isolated rather than as a part of the integral governance of agrarian and rural sustainability. The Bulgarian experience indicates that such a unilateral approach can hardly achieve projected results. First, economically and/or socially unviable farm structures can be sustainable in the environmental sense. Indeed most environmental problems in Central Asia could be related to the low efficiency (and sustainability) of different type farms. Since farms perform multiple functions, including production, minimization of transaction costs, and environmental preservation, all of these functions are to be taken into account when we assess farm efficiency (Bachev, 2004).

Next, ignoring the "environmental aspects" of development has been responsible for much of the harmful impacts of farming (and other industries) in developed, transitional, and developing countries. Therefore, all (economic, social, environmental, intra- and inter-generational) aspects of sustainable development are to be taken into account when we design or select the effective modes of governance in Central Asia.

The new integral framework requires a novel approach to organization and management of public support, research, education, and extension programs. It necessitates inclusion of all dimensions of sustainability in priority setting, criteria selection, implementation, and impact assessment of every program. In particular it calls for multidisciplinary analysis of agrarian modernization and governing structures dominating in different farming sectors, regions, and countries. Increasingly, public support should embrace larger actions of farmers and rural agents, including projects supporting environmental and biodiversity preservation, integration of farming into agro-tourism and the food chain, and diversification of rural economy in renewable energy and services.

3.3. NEED FOR PUBLIC INTERVENTION

Market competition and private organization contain strong coordinating and incentive advantages. However, they are not sufficient since they fail to provide a socially desirable level of environmental preservation and improvement or may need a very long time to supply them on an effective scale. In the case of Bulgaria, market driven organic farming took 10 years to emerge, and its scale is only a tiny proportion of the existing technological, market, and eco-potential. Similarly, private and collective environmental action organizations are still in the formation stage. That is why public intervention could significantly facilitate development of market and private modes. In Bulgaria, the state regulation, certification, and subsidies for conversion to organic farming and farm energy production aim at accelerating expansion of these prospective modes.

In Central Asia, public intervention from government and local authorities should focus first of all on defining and enforcing "rules of the game" by introducing new property rights to natural, biological, and environmental resources, and effective system(s) for enforcement of these rights.

Secondly, public authorities have to use their power to introduce modern eco-regulations (standards, norms, and quotas) for: (1) use of inputs, natural resources, and technologies; (2) harmful emissions; (3) contamination of water, soil, and air; (4) waste management; and (5) product quality and safety. The latter could effectively assist and/or frame actions of market and private agents in achieving environmental goals of development.

Next, post-communist transformation in all countries has been associated with the relaxation of environmental pressure and "improvement" of the eco-situation. In recent years, a reverse trend back to intensification and over-exploitation of natural resources has been observed in the region. In order to prevent recurrence of the negative effects of the past intensification and mismanagement, it is urgent to institutionalize current “achievements” in the area. Unless appropriate public measures are put in place to preserve and improve the current state of the environment (e.g. new eco-norms), the adverse trends driven by market and private incentives could prevail.

Fourth, an important public role is to provide up-to-date monitoring and information about environmental problems and risks caused and/or affected by agriculture. For some Central Asian countries such a system would need to be improved not only in terms of technical precision but with respect to securing full independence from authorities.

Fifth, a crucial public role is to educate and advise producers and consumers on environmentally sound production, consumption, and governance modes. Looking for positive (and negative) local and international experience and disseminating it in the region would be especially important.

Finally, institutional reforms and restructuring of transitional economies is inevitably associated with lower sustainability of some farming structures and the emergence of a huge informal sector. In order to avoid the negative experiences of Bulgaria, Central Asian countries should undertake special measures to attain the desired level of environmental management. This could be achieved through assuming the liabilities of liquidating publicly owned farms, delaying or accelerating the reorganization of public agencies responsible for eco-management, and increasing public support for eco-activities of private organizations. Along with that, programs and incentives for commercialization, expansion, association, and diversification of smaller and subsistence farms need to be introduced.

Bulgarian experience demonstrates that a considerable informal (gray or black market) sector will continue to exist for a long time, and there will be technical and political difficulties in establishing an effective system of public governance and control. Here, individual “punishments” do not work well, and overall damage to the environment from the sector are immense. That is why policies should be directed toward the market orientation of subsistence farms, support and incentives for collective modes, and eco-programs for informal farms and groups.

3.4. THE NECESSITY FOR DIRECT PUBLIC SUPPORT

Many environment-related activities are associated with significant positive or negative externalities. Low appropriability of eco-investment and rights makes it very costly to protect absolute and contractual rights and profits through market and private modes (Bachev, 2007a). Thus, the public role must not be limited to a supreme legislator and judge. Effective environmental management cannot be achieved without direct public involvement in environmental preservation and improvement.

More particularly, in Central Asian countries direct public support is to focus on following:

Firstly, it is imperative to define and finance farming multi-functionality. When costly "public goods" are to be provided by farmers (e.g. preservation of the environment and biodiversity, as well as preservation of traditional production practices and varieties), they have to be effectively funded by the state budget. Here neither pure administrative measures nor market competition and private (voluntary) initiatives can be effective. Central Asian countries possess dissimilar budgetary capacity to fund such "new" farming functions. However, each country has to recognize the farmer's role, set attainable goals, select effective modes for implementation (eco-subsidies, contracts, etc.), and provide the necessary funding to achieve these objectives. In the same way, when significant "non-productive" investments are to be made to benefit the entire food chain (e.g. adaptation to new standards for food-safety and animal welfare) they are to be financed by the public or shared by all stakeholders, including farmers, processors, retailers and final consumers.

Second, in many Central Asian countries there is an urgent need to modernize rural markets and infrastructure, including transportation, telecommunication, and waste management. State and local governments have to provide these elements important for sustainable development in adequate scale and quality. Bulgarian transformation, for instance, implies that farm-related waste could be more effectively managed if public agencies initiate, build and maintain a network of solid waste disposal sites in rural areas.

Third, public agencies should foster farming associations and cooperation. Similar to those in Bulgaria, farmers in Central Asia are small-sized and diversified in terms of scale and structure of production, orientation, experience, and age. Farming cooperation could bring significant technological and transaction benefits to small-scale farmers, including collective exploration of economies of scale/scope in supply of inputs, marketing, access to public support and eco-programs. Therefore, public support is to be given to grouping, cooperation, and association of small-scale farmers through assisting with registration and organizational development, as well as providing independent financial controls and tax breaks.

Fourth, the public should subsidize eco-friendly projects of private and collective farmers. Effective public demand for eco-services would accelerate the development of diverse private and collective initiatives, such as codes of conduct and environmental enhancement activities. The experience of Bulgaria proves that some of the standards and terms of contracts for environmental and biodiversity conservation, animal welfare, and cultural preservation are very difficult or even impossible to enforce and dispute. Most likely, compliance would be even lower in Central Asia, where inefficient administrative institutions and "personal relations" dominate. Therefore, providing public support to voluntary initiatives of farmers and rural organizations in the form of information, training, organizational development and funding would be much more effective than other modes in terms of incentive, coordination, enforcement, and dispute costs.

3.5. TYPES OF PUBLIC AND INTERNATIONAL ASSISTANCE

Frequently, public and foreign aid programs try to apply international experiences to the specific conditions of transitional countries. The Bulgarian transformation demonstrates that a great deal of UN, World Bank and other programs failed to achieve desired results because they were not well-adapted to specific local markets and institutional and natural environments. In addition to pure technical aspects, that is especially important as far as adaptation to formal and informal institutional structure is concerned. Each Central Asian country has a unique institutional arrangement of farming determined by property rights, past experience, culture, tradition, religion, and other factors, which all have to be taken into account when designing or adapting modes of governance. An arrangement that works well in one country with good administration and rule of law could fail in a situation of social disorganization and domination of informal links and corruption.

Likewise, it is very important to incorporate the environmental concerns and initiatives into the existing system of governance (and power) in every country. For instance, certain countries in the region still employ mandatory quotas on major agrarian resources and outputs and state run, vertically integrated channels for the supply and marketing of inputs. These systems could be used to achieve some environmental goals if appropriate technologies, crop structures, and allocation of inputs are applied. Also, a requirement of "cross-compliance" with minimum eco-standards could be introduced into the current system of public support in order to improve the eco-performance of farms.

Furthermore, all aspects of sustainability are to be taken into consideration when a specific governing mode is assessed. For instance, the introduction of an eco-tax on inputs, resource consumption and emissions works well in a number of developed and transitional countries. However, the same measure could be inefficient or even harmful to the environment in Bulgaria and Central Asia. Here, most farmers are poor and receive less support from the state. As such, there are disproportionate dynamics in the prices of farm products and inputs, and unbalanced fertilizer compensation (N, P and K) is typical. In addition, Central Asian agriculture is mostly oriented toward the production of raw materials for highly competitive (often subsidized) international markets, and tax collection systems do not work well.

One significant shortcoming of much of the state and international assistance in Bulgaria has been the lack of a long-term perspective. In Central Asia success in environmental and rural development issues would also require support programs to set up and commit financially to long-term goals. If these long-term goals are not established, and project objectives are not aligned with these goals, "project failures" will continue.

Most public assistance programs do not provide equal access to all farmers. The Bulgarian experience shows that it is not the most needy farms that commonly benefit from public support, but rather the larger, more powerful, and better connected (often corrupt) farms. In Central Asia special measures should be taken to guarantee fair and equal access to aid programs for smaller-scale farms. This can be achieved by adjusting program requirements to include maximum size, structure of production, cost-sharing potential, project preparation capacity, and feasible implementation terms. Without these controls, existing economic, social, and environmental disparities among different farms, sub-sectors and regions would be sustained or exacerbated.

Last but not least important, improvement of the governance of any public mode cannot be achieved without direct involvement of farmers and other stakeholders in program management. The participation of farmers and interest groups at all levels would improve information, adaptation, control, motivation, cost-sharing and impact capacity of environmental management. Principally, hybrid modes (public-private partnerships) are much more efficient than pure public forms given the coordination, incentives, and control advantages (Bachev, 2004). In the majority of cases, the involvement of farmers, farm organizations and other beneficiaries would increases efficiency by reducing asymmetry of information, restricting possibilities for opportunism, and diminishing management and implementation costs. Hybrid modes also contain stronger incentives for farmers' involvement and cost-sharing. In Central Asia employment of such modes in farming infrastructure and eco-projects would be particularly effective, since inflexible centralized forms dominate and serious funding deficiency exists.

3.6. FRAMEWORK FOR IMPROVEMENT OF ENVIRONMENTAL MANAGEMENT

The persistence of serious environmental problems and risks indicates that an effective system of environmental governance is not yet in place. The first step in improving environmental management is to identify the existing and potential new problems and risks. Modern science offers precise methods to detect environmental problems associated with agriculture and improve farming practices in order to mitigate various environmental hazards.

Secondly, we have to identify the spectrum of market, private, public and hybrid modes of governance employed in farming, assess their efficiency in terms of eco-management, and specify major factors for their “failures”. We also have to estimate the potential of existing and other feasible governing structures to deal with emerging environmental problems and risks in the conditions of each country.

Next, the major failures in dominating market, private, and public structures to solve existing and emerging environmental problems are to be specified, and the needs for new forms of public intervention identified.

Finally, it is necessary to identify feasible modes of public involvement in environmental management, assess their comparative efficiency, and select the most efficient option(s).

Usually individual modes are effective if they are applied along with other modes of public intervention. The necessity of a combined intervention (governance mix) is caused by the complementary nature of different forms; the possibility to gain extra benefits (e.g. cross-compliance); particularity of environmental problems to be tackled; character of activities; uncertainty associated with the impact of new forms; the administrative and funding capability of government; and dominant policy doctrines and/or priorities of international donor organizations.

The level of effective public intervention depends on the kind of environmental problems and risks. There are public involvements which can be executed at a local (community or regional) level, while others require national oversight. Additionally, there are eco-activities that should be initiated and coordinated on an international (bilateral, regional or worldwide) level due to the necessity for cross-border actions (needs for cooperation in environment management, exploration of economies of scale/scope, and governance of spill-overs)[1] or consistent national and/or local government failures. Often, effective environmental management would require multilevel governance with combined actions of various stakeholders.

At this stage of analysis we could also predict the likely causes of public failures due to impossibility to mobilize sufficient political support and necessary resources and/or ineffective implementation of “good” environmental policies. Since public failure is a possibility, its timely detection permits environmental managers to foresee the emergence or persistence of

[1] The recent epidemic of avian flu is a good example.

certain environmental problems and to inform local and international communities about associated risks.

4. Conclusions

We proved that contemporary environmental problems in Bulgarian agriculture have been consequences of dominant modes of governance over the last 15–20 years. We also demonstrated that the Bulgarian experience in environmental management could be effectively used in Central Asian conditions. Countries from the region could adapt the positive market, private, public and hybrid modes of environmental governance from Bulgaria to their specific economic, institutional and natural environments. Furthermore, they could avoid the occurrence of significant management failures and negative experiences of Bulgaria if adequate preventive or proactive measures are put in place.

More particularly, the Bulgarian transition experience provides lessons for Central Asia in:

- Directions for modernization of institutional structures through the introduction of new eco-rights, redistribution of rights to natural resources, liberalization of eco-activities, and improvement of enforcement of eco-rights
- Adopting an integral approach to governing public support, research, education and extension programs embracing economic, socio-political and environmental aspects of agrarian sustainability
- Selecting more effective modes of public intervention (regulation, development assistance, financing, and partnership with the private sector) and enhancing direct public involvement in environmental preservation and improvement
- Improving different forms of public and international assistance through incorporation of environmental measures in dominating modes of farming governance in each country; taking into consideration all advantages, disadvantages and impacts of individual forms; committing to and effectively funding achievement of long-term goals; securing equal access of all types of farms to support programs; and involving farmers and other stakeholders in program management and implementation

We also demonstrated that comparative institutional and transaction cost analysis could enhance significantly the process of improvement of environmental governance. Studies on specific experiences with environmental management in transitional countries and possibilities for its adaptation elsewhere should be expanded to new aspects and regions.

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Cotton field near Mardon Qishloq, Uzbekistan, October 2007.

IRRIGATION OF THE AMU DARYA BANKS AND ITS ROLE AS A POTENTIAL SOLUTION FOR THE POPPY PROBLEM

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Abstract. Depletion of water resources requires us to search for less conventional strategies for water preservation and irrigation. Sustainable management of such water resources along with the development of sustainable irrigation systems will contribute stability to agricultural yield – a primary concern in all riparian countries, like Uzbekistan, Turkmenistan, Tajikistan and Afghanistan. This paper attempts to identify priorities in reconstruction assistance planned for all riparian states on the Amu Darya. The problems of growing, processing, and trafficking illicit drugs in Afghanistan is then analyzed, searching for the economic, social, and political causes, with an emphasis on its implications for the future development and the geopolitical picture of the Central Asian region.

Keywords: Afghanistan, Amu Darya, Central Asia, drug control programs, subsurface drip irrigation (SDI), poppy fields, Uzbekistan, water resources

1. Introduction

More than ten million residents in north Afghanistan and Central Asia have been suffering from desperate famine, drought, and poverty. People of Afghanistan have suffered greatly at the hands of foreign powers for decades and have witnessed an almost unprecedented destruction of their cultural and educational infrastructure, industries, and agriculture. Much of the world's attention on Afghanistan is now focused on the military actions

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of OEF,[1] ISAF,[2] and others, despite no visible exit. The most crucial security problem in present day Afghanistan is widespread corruption in the country.

The monoculture economies of Central Asia's republics, imposed by the former Soviet Union, make it difficult to upgrade their economies in line with modern market models. Such changes require a new look not only at domestic but also interstate aspects of their economies. Afghanistan can hardly attain effective reconstruction without both the knowledge and experience in irrigated farming in arid climates that people from the former Soviet republics can offer and cooperative improvements in agriculture and water resource usage in those republics.

Illicit drugs are also a global problem with more than 200 million people abusing drugs worldwide. Afghanistan is a major player in this drug problem and is itself often viewed as a culprit in this phenomenon (e.g., Afghanistan now accounts for 93% of the global production of opium, up from 70% in 2000). Drug abuse is responsible for great losses from societies' financial resources, high expenses in efforts aimed at containment, and the costs of broken families and deteriorating communities. Drugs are directly linked with rates of violence and terrorism. Drug cartels undermine governments and corrupt legitimate businesses. Revenues from illicit drugs fund many of the armed conflicts throughout the world.

Can science provide any remedies for the largely remaining residue of such human catastrophes and contribute much-needed solutions to help associated societies overcome their current problems?

2. Irrigated agriculture and development

Uzbek irrigated agriculture is characterized by high average crop yields when compared with the yields of other Central Asian riparian countries. This apparent success can be attributed to an excess use of water resources. This situation to meet agricultural water demands is remarkable in view of Uzbekistan's total dependence on irrigation water from the Amu Darya, the Syr Darya, and other rivers. There is increasing pressure on this limited water supply. Nevertheless, there are excellent opportunities for adding to the value of agricultural outputs, especially in the plains and foothill areas. On the other hand, several trends reveal the future likelihood that productive agriculture in the Amu Darya Basin will face hard times.

[1] Operation Enduring Freedom (OEF) is the official name used by the United States government for its military response to the attacks of 11 September 2001.

[2] International Security Assistance Force (ISAF) is the name of a NATO-led security and development mission in Afghanistan which was established by the United Nations Security Council on 20 December 2001.

The opium poppy is a labor-intensive crop. Estimates suggest that approximately 350-person days are required to cultivate one hectare of poppies for opium in Afghanistan, as compared with approximately 41-person days per hectare of wheat. Opium harvesting alone is reported to require as much as 200-person days per hectare. Consequently, to spread out the demand for both hired and family labor during the harvest period, households both cultivate different varieties of opium poppies with differing maturation periods and stagger the planting of opium poppies. Poppies are harvested in March and April. However, despite using this method and all these efforts the majority of opium producing households must still hire labor during the opium poppy harvest.

3. Principles of and a mechanism for subsurface irrigation

Many local and foreign experts consider subsurface drip irrigation (SDI) systems available today to be among the most rational and effective of irrigation technologies. The concept of SDI has more than a century of history. In many advanced countries, scientists have studied this advantageous type of irrigation for many years. In the Soviet Union, the study of SDI began in 1923. It did not find wide application until the 1950s due to a lack of access to cheap and durable materials required for installation and maintenance. This irrigation system has been developed on a large-scale for the serosems soils of Ukraine, the Caucasus, and to a lesser extent the countries of Central Asia.

Research on this system has been conducted for many years in order to promote the system and adapt it to the conditions of Uzbekistan. First, the moistened polyethylene perforated tube system was applied in 1967 in the Tashkent region on the experimental plots of the All Union Institute of Agriculture. In 1970, systematic scientific research on the application of subsurface irrigation system began during the initiation of agricultural development projects in the Golodnaya Steppe's virgin lands. This type of new technology was used in the cultivation of traditional crops, in particular cotton on many of the collective farms there.

SDI involves supplying water to crops through special moistened pipes that are laid in rows on arable lands. Water flows through these pipes due to a low-pressure head, and the water moves vertically to the plants' root systems due to the soaking up force of the soil (i.e., capillary pressure). It is possible to adjust the SDI system precisely to allow for air-moisture soil conditions, as well.

Settling-tanks should be constructed before the installation of any pipe system. Their mechanism for operation is based on the sedimentation of mechanical silt/dust particles, as well as a precipitation of many heavy cations (Al, Mg, Ca etc.) that easily lead to the up silting and/or corking of tubular pipes. The use of clean/pure and non-saline water is thus more efficient, particularly for the development of SDI system in Uzbekistan.

The effectiveness of an SDI system is also determined by crop variety and mostly by root system morphology. Cultivated fodder grain, legumes, melons, and gourd crops respond positively to the subsurface irrigation, while in the case of fruit trees the height of their root system leads to the corking of pipe perforations. In such cases, drip irrigation seems to be one of the most effective technologies for viticulture and horticulture development. For prevention of secondary soil salinization, crop rotation should be used. For example, it is recommended to harvest rice after other crops have been harvested for 3–5 years.

Drip irrigation is the most appropriate technique for desert agriculture because it can reduce salinity levels and thus save farmlands from destruction. Drip irrigation is thus an essential technology in both sustaining agricultural production in the region and preventing permanent destruction of farmlands.

Drip irrigation will allow a water savings of between 60% and 70%. By eliminating the use of excess water, the drip system prevents a rise in underground water tables and thus diminishes the risk of salinization. Drip irrigation also allows for using irrigation waters with higher salinity contents. When clear guidelines on application rates and frequencies are adhered to, drip irrigation minimizes potential risks of saline water to both crops and yields. Drip systems also allow farmers to reclaim land suffering from salinity problems. Drip systems will increase crop yields by an average of between 40% and 50%, and even by much more in some cases.

Additionally, drip irrigation permits an expansion of cultivated irrigated land (up to three times the current area). Drip irrigation allows farmers to adopt better crop varieties, to increase yields, and to improve crop quality. Drip irrigation reduces the non-yielding period of young orchards, with a first yield at least one year earlier. Drip irrigation also enables farmers to adopt crop production alternatives that can better compete with the high incomes that are otherwise available from the production of opium poppies.

With additional technology, such as high plastic tunnels, it is possible to produce as much income from vegetable crops as farmers earn presently from the production of poppies. Experience with drip irrigation in arid areas around the world proves that integrated technology systems based on drip irrigation are feasible and economic. It is almost the only way to guarantee sustainable agricultural production in desert areas. The current large-scale cultivation of poppies in each province of Afghanistan is the result of a suitable winter climate for poppies as well as a lack of viable alternative crops. Since the ability of the government to directly eradicate poppy production is very limited, the best way to reduce poppy production in the area is to provide farmers with viable alternative crops and with the appropriate technologies that will provide high incomes from traditional crop production.

4. Agriculture in North Afghanistan

The Kyoto University Scientific Mission to Iranian Plateau and Hindukush has been conducted since 1955. The research team of the 5th Scientific Mission to Iranian Plateau and Hindukush left for Afghanistan in 1964. One of the objectives was to investigate agricultural districts in the provinces of Herat, Badghis, Faryab, Jawzjan, Balkh, Samangan, Kunduz, Takhar, and Badakhshan.

Double cropping was very common in those semi-arid regions. Farmers generally harvested wheat or barley in winter and cotton, beet, or melon in summer by lift brook irrigation. Irrigation canals we saw on the Right Bank of the Amu Darya are hardly seen there those days. *Qanat* or *karez*, which are subsurface water channels, were used to provide drinking water to local residents, but they were not providing enough water to harvest crops. Single crop rice fields with bunded irrigation were seen near the cities of Khanabad and Kunduz in Kunduz province.

The Right Bank of the Amu Darya has been a highly productive land for irrigated agriculture. Besides, some new irrigation technologies such as SDI are available to increase production and to improve yields of crops. These technologies also enable us to cultivate crops that we cannot cultivate with limited water resources in the semi-arid region so far. We assume that the Left Bank of the Amu Darya possesses equivalent edaphic and agricultural potential compared with the Right Bank.

5. The framework of regional cooperation

There have been two international freshwater treaties for the Amu Darya that have been signed by the Central Asian republics. However, neither of these treaties has included Afghanistan.

The first treaty was "Agreement on joint activities in addressing the Aral Sea and the zone around the Sea crisis, improving the environment, and enduring the social and economic development of the Aral Sea region (1993 Agreement)," signed on 23 May 1993. It said that republics knew there were some issues relevant to environmental degradation and inadequate water use in the Aral Sea basin. Hence, interstate coordination would be required to solve the issues. Nevertheless, water resources allocation was not covered in this treaty. Four intergovernmental institutions were approved by this agreement: the Interstate Council on the Aral Sea Basin (ICAS); the Executive Committee of ICAS (EC-ICAS); Commission of Social and Economic Development and Cooperation in Scientific, Technical, and Ecological Spheres; and Coordinating Commission on Water resources, acting as the Interstate Commission for Water Coordination (ICWC) in conformity with the agreement signed on February 18 in 1992.

The second treaty was “Resolution of the Heads of States of the Central Asia on work of the EC of ICAS on implementation of Action Plan on improvement of ecological situation in the Aral Sea Basin for the 3–5 years to come with consideration of social and economic development of the region (1995 Agreement),” signed on 3 May 1995. The agreement also consisted of seven resolutions and one joint declaration. The joint declaration was composed of five articles. Those articles were the same as those in 1993. The seven resolutions contained the clarification of establishing the International Fund for the Aral Sea (IFAS), and the Executive Committee of IFAS (EC-IFAS). The new IFAS was established in 1997 as a successor to the former ICAS and IFAS. The International Fund for the Aral Sea (IFAS), 1994, provides funds for protection of Aral Sea. Setting up ICAS and EC-ICAS was the main purpose of this treaty.

6. The need for interstate coordination

A number of researches have concluded that a legal and institutional framework was required for the cooperative management of scarce trans-boundary water to resolve unsustainable economic practices, environmental degradation, and serious social problems in the Amu Darya basin. The first question should be whether or not this is true.

E.A. Chait (2000) has done an interesting analysis in a working paper, “Water Politics of Syr Darya Basin, Central Asia: Question of State Interests.” According to the paper, the national leaders of the Central Asian Republics believed that the cooperative management over shared trans-boundary water resources was not a better option for achieving their own political and economic goals. The reason why they thought like that was the conservationist water management schemes proposed by the international organizations such as the World Bank and United Nations Development Program (UNDP). Those schemes did not fit the republics’ agenda reflecting economical development. Besides, their ineffective continuous investments in regional institutions have disappointed national leaders and upper echelons of republics.

Karimov and McKinney (1996) reported that there was a need to develop a basis for international water law to regulate the republics’ relations, their rights and responsibilities, and coordinate their measures for interstate administration of the Amu Darya basin, data collection for water allocation, and common planning needs. In their contents, they placed an emphasis on pricing water properly to attain optimum water resources allocation.

Langford and Vinogradov (1999) concluded that legal and institutional mechanisms played an increasingly important role in cooperative efforts to manage trans-boundary water resources in the Aral Sea basin, including the Amu Darya basin. The mechanism critical to achieve includes equitable and reasonable utilization. The obligation was not to cause significant harm to other republics and sustainable development. These criteria have been stated in Article 5, the Draft Articles of the Law of Non-Navigational Uses of International Water Courses, approved by the General Assembly of United Nations in 1997. They also described that the development of hydrocarbon resources could promote the solution of conflicts relevant to the difference between upstream power generation in Tajikistan and downstream irrigation in Uzbekistan and Turkmenistan in terms of seasonal demands for water.

International law in the Amu Darya basin should be developed to achieve the optimum trans-boundary water resources management. The law must be enforceable for any riparian states including Afghanistan located in the Left Bank of the Amu Darya. Presence of free riders invalidates the law. Therefore Afghanistan must be contained in the interstate coordination.

7. Opium production and traffic routes

While much of the Southeast Asian crop finds its way to the United States, Europe is the main destination for heroin coming from Afghanistan. According to the US Drug Enforcement Agency (DEA) Afghanistan had the potential to produce 4,950 t of oven-dried opium, up from 2,865 t in 2003, and 1,278 t produced in 2002. According to the United Nations Office on Drugs and Crime (UNODC), Afghanistan now accounts for 93% of the global production of opium, up from 70% in 2000. These are then transported through a number of intermediate countries, where it is sometimes further refined and processed, and finally shipped to Europe and North America. Afghanistan has become the most dangerous narcotic country in the history.

Political and military events after September 2001 have changed the situation of poppy fields and may further change it in the coming years. Illicit opium poppy cultivation increased in the parts of Afghanistan controlled by the Northern Alliance and recently has expanded to other districts, many of which are close to the northern border of Afghanistan. Opiates originating in Afghanistan continue to be smuggled into and through Iran and Pakistan. There has been a significant increase in the quantity of drugs from Afghanistan seized in some countries in Central Asia.

The current government in Afghanistan has banned opium trade and also instituted an especial commission to follow this ban. This commission has approved a compensation of $350.00 for burning every acre of land (about a fourth of a hectare in Afghanistan) under opium cultivation but this is not a considerable amount as such an area of land can produce five kilos of opium extract worth $240.00. So farmers could get $1,200.00 if they sell the harvest of opium in the market. In a situation like this, they might bribe the government officials to keep the poppy cultivation on their land, and the current estimation of 3,500–4,000 t of opium production point to the same possibility.

We still can see all the ingredients for illicit opium cultivation in parts of Afghanistan: civil war, an absence of law and order and no alternative for farmers. The criminal gangs who control the refining and shipment of heroin are still very much in place.

8. Discussion

We are witnessing how the population of the Aral Sea Basin countries is continuously growing and the demand for fresh drinking water, local food production and more employment opportunities is gradually increasing. We are proposing a critical long-term resolution to achieve this aim. Agricultural development using SDI for crops such as rice on the Left Bank of the Amu Darya (Afghanistan) is what we suggest. The former Soviet Union and Central Asian Republics have irrigated the Right Bank of the Amu Darya (Uzbekistan and Tajikistan) since the end of the 19th century. On the contrary, the Left Bank of the Amu Darya has been ignored though its soil, climatic and agricultural potentials are almost equal to the Right Bank. Our proposal is to build permanent food production systems on these forgotten dry lands to help feed Afghan people and to provide them with jobs.

Actually, several rehabilitation plans in Afghanistan are ongoing. The United Nations Food and Agriculture Organization (FAO) have distributed 1,500 t of wheat seed to approximately 30,000 families in rural areas of northern Afghanistan. The United Nations World Food Programme (WFP) is also set to shift the focus of its operations from relief to rehabilitation. WFP has announced a new nine-month emergency operation that uses innovative food aid projects to help millions of Afghans re-establish their shattered lives and build the future for their devastated country. This $285 million operation will provide Afghan people not only continuous emergency food aid, but also foundations for reconstructing the devastations by the 3-year-drought and the two-decade-war. The operation will also fund a series of rapid impact programs designed to reconstruct basic infrastructures such as irrigation systems.

Nevertheless, these irrigation systems require much water from watercourses including the Amu Darya and its tributaries such as the Kunduz River, and the Pyandzh River. Afghanistan has not participated in the interstate agreement for trans-boundary water resources of the Amu Darya. It is easy to infer what may happen next. Conflicts between Afghanistan and the Central Asian Republics may occur. In the worst possible case, these conflicts might bring another tragedy to Afghanistan. Therefore, it is inevitable to arrange the interstate coordination for trans-boundary water use among all riparian states before the rehabilitation plan for Afghan irrigation systems is promoted.

9. Conclusion

There are four conditions necessary to attain equitable, reasonable, and optimal utilization of Amu Darya water resources among all riparian states. First, sophisticated interstate agreements for water use must be signed. Second, all riparian states (i.e., Uzbekistan, Tajikistan, Turkmenistan, and Afghanistan) must participate in any agreement. Third, an independent institution with superior authority for water use of all participants must be founded. Without these conditions, we shall not be able to achieve effective reconstruction assistance to Afghanistan. Fourth, some of the Afghanistan Reconstruction Funds must be allocated to co-improvement of water use efficiency and agricultural development for all riparian States.

International Law Commission (ILC) had developed the draft articles on the law of the non-navigational uses of international watercourses in 1994. Then, the General Assembly of the UN approved the draft articles in 1997. These articles have become the common legislative framework for international watercourses since then, although they still seem deficient. Article 4 says that every watercourse state is entitled to participate in the negotiation, and to become a party to any watercourse agreement that applies to the entire international watercourse, as well as to participate in any relevant consultation. The second provision says that a watercourse state user of an international watercourse that may be affected to a significant extent by the implementation of a proposed water agreement that applies to only a part of the watercourse or to a particular project, program, or use is entitled to participate in consultations on, and in the negotiation of, such an agreement, to the extent that its use is thereby affected, and to become a party thereto. Therefore Afghanistan is entitled to participate in a proposed water agreement such as the 1993 Agreement and 1995 Agreement signed by the Central Asian states according to the Article 4.

An independent juristic body is required to settle an interstate dispute. Existing institutions such as ICWC, ICAS, and IFAS are not juristic institutions and are not able to prescribe interstate water law, do not have authority of compulsory execution, and settle disputes. They are not legislative organizations either. Since Central Asian Republics did not have a place for dispute settlement, a serious dispute occurred between Kyrgyzstan and Uzbekistan in 1997 due to the difference in seasonal water demands. Kyrgyzstan finally decided that most of its water resources would be introduced into hydroelectric power generations in 2001 to complement energy shortage.

To settle this kind of dispute, all riparian states must entrust authority of water allocation to the independent juristic institution whose major objective is to achieve equitable and optimal water resources allocation among all riparian states based on the sophisticated international water law. The institution should consist of independent judges and agents independent from riparian states. They can be of foreign origin such as Russia or Japan. Without the settlement system of dispute, it is very difficult for riparian states to achieve peaceful optimal water resources allocation.

Interstates coordination of water use by the independent juristic institution helps achieve optimal water resources allocation and peaceful settlement of disputes. Sophisticated interstate water law provides fair provisions. Funds must be provided to facilitate the above-mentioned activities to reconstruct Afghanistan and the Central Asian states.

It can also be concluded that addressing the serious drug control situation in Afghanistan needs the support and cooperation of the international community, in particular the neighboring countries. Achieving peace, security and development in Afghanistan is closely linked to the solving of the drug control problem.

The international community can address the opium problem in Afghanistan by assisting its agricultural economy to get back on the right path. Afghanistan needs a comprehensive strategy that can provide sustainable alternatives to poppy cultivation. Wheat, rice and cotton are the most widely touted alternatives to poppy for local farmers. But to flourish, production would need far more rain than the region has received, and large-scale improvement of irrigation facilities across the region is necessary.

The key is to mobilize resources from the international community to provide farmers with the irrigation, seed, fertilizer and machinery they need to raise alternative crops. Priorities include repair of irrigation systems, provision of improved seeds and fertilizer, and assistance with market access.

With our short discussion on all the social, economical, political, and humane perspectives of the opium issue, the importance of providing a competent system of irrigation for the farmers living in north Afghanistan could not be overemphasized, considering the potentials of the Amu Darya to support a healthy and strong agriculture on its left bank.

Also credit must be offered to local farmers to help them escape the debt trap. Many farmers are in debt to local drug lords who demand that they grow poppies. Even farmers who cultivate cereals struggle to feed themselves, as entire harvests taken to repay the debts they accumulate. Apart from long-term restructuring plans, they also need immediate assistance.

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Poppy field in Afghanistan.

USING A VALUE CHAIN APPROACH FOR ECONOMIC AND ENVIRONMENTAL IMPACT ASSESSMENT OF COTTON PRODUCTION IN UZBEKISTAN

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Abstract. Cotton in Central Asia has a reputation for causing the twentieth-century ecological catastrophe known as the Aral Sea crisis. The cotton industry was blamed for political repression, economic stagnation, widespread poverty and environmental degradation in the region.[1] The cotton monoculture practices imposed during the former Soviet era not only diverted massive amounts of water from the Amu Darya, one of the two main feeders of the Aral Sea, but also caused ecological problems, such as desertification, water and soil salinization, and air and water pollution due to the run-off of pesticides and fertilizers. The consequences and environmental costs proved to be drastic: dying of the sea, deterioration of the environment for more than five million people living in the region of the sea, high rates of disease incidents, as well as even farther-reaching ecological problems. However, cotton is of paramount importance to Uzbekistan, a backbone of its economy. Not only it does account for a considerable share in foreign exchange revenues and GDP, but it also provides employment and income security for a large share of the rural population. Concurrently, affected by fluctuations in prices on the world cotton market, the export of cotton fiber caused the government of Uzbekistan a loss of about US$1.5 billion

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[1] International Crisis Group, 2005.

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between 1998 and 2001.[2] Hence a continuation of the cotton monoculture and export of low value fiber can no longer be regarded as the vehicle for permanent, broad-based, and environmentally sustainable growth. A shift from the primary commodity exports to the export of value added cotton products and the removal of trade barriers became a key aspect of recent reforms. There is definitely scope for maintaining and even increasing the returns from cotton without an increase in cotton areas. Decreasing cotton areas, shifting land unsuitable for cotton to other crops, or establishing alternative uses such as tree plantations or pastures can contribute greatly to ongoing attempts to prevent or mitigate further aggravation of the ecological situation in the region. Value Chain Analysis was applied in the study region Khorezm to get a comprehensive picture of the entire cotton sector by describing the cotton flows, actors involved and their interrelationships, costs of production, and income distribution along the cotton chain. This approach allowed the assessment of some scenarios aimed at reducing the dependence on cotton while maintaining income both to the state and the farmers, as well as the estimation of ecological impacts of reforms in the cotton sector. For example, export revenue of the baseline scenario could be maintained with a simultaneous reduction in raw cotton areas of 3.5 times, in the Khorezm region alone. Under this scenario, about 80,000 ha could be released from state orders and diversified for alternative crops or land uses (tree plantations or forage crops), thus making agriculture more environmentally friendly while maintaining its economic importance.

Keywords: Environmental degradation, Central Asia, Aral Sea

1. Introduction

The Aral Sea is shared by the Central Asian countries Kazakhstan and Uzbekistan. Since ancient times it has been known as an oasis and was populated by *traders, hunters, fishers, and merchants.*[3] Up until 1960s it was considered the fourth largest endorheic body of fresh water in the world, but the sea has shrunk by more than two-thirds, and its depth fallen by more than 14 m.[4] The drying of the sea has gained global attention as one of the greatest man-made natural disasters in the world.

[2] Washington Conference on Cotton and Global Trade Negotiations, 2002.
[3] http://www.africanwater.org/aral.htm
[4] http://news.bbc.co.uk/onthisday/hi/dates/stories/october/22/newsid_3756000/3756134.stm

The drastic shrinkage of the sea was caused by the diversion of the two rivers that feed the sea, the Amu Darya and the Syr Darya, for irrigation of the vast areas to the south of the Aral designated to grow cotton. Today Uzbekistan is one of the world's largest exporters of cotton, but the extreme shrinkage of the sea has altered the climate and the livelihood of millions of people. Winters became colder and summers hotter and dryer. The ecosystem of the Aral Sea and the river deltas has been nearly destroyed, and biodiversity has decreased.[5] The former seabed represents huge plains covered with salt and toxic chemicals, about 100 million tons of which annually are picked up and transported by the winds throughout the surrounding area. Pollution was aggravated by weapons testing, fertilizer and pesticide runoff. More than five million[6] people suffer from a lack of fresh water and numerous health problems, which is perhaps the most significant factor of the Aral Sea crisis. Mortality rates have radically increased, while life expectancy and quality have declined. Cancer, tuberculosis, asthma, chronic gastritis, heart and kidney malfunction, and anemia are widespread. The once thriving fishing industry has been destroyed leaving thousands of people unemployed, and the performance of the vital agricultural sector continues to drop.

Meanwhile cotton, which is reputed to have caused the ecological catastrophe of the Aral Sea, remains and will continue to be Uzbekistan's most important sub-sector and largest export earner. Uzbekistan ranks worldwide as second in cotton fiber export, with 0.7–0.9 million tons of cotton fiber exported annually, and is the sixth largest cotton producer (approximately 3.5 million tons of raw cotton and 1.2 million tons of cotton fiber produced annually).[7] Hence, cotton constitutes about 13% of Uzbekistan's GDP, accounts for around 25% of its foreign exchange revenues, and provides the basis for roughly 20–30% of the country's rural employment. Concurrently, cotton production utilizes 41% of all irrigation water and about the same amount of all irrigated land.[8] Cotton also created a network of other industrial branches including irrigation networks, machine building plants, chemical facilities, hydro-electricity, cotton-processing and some textiles.[9]

Yet, owing to fluctuations in prices on the world cotton market, the export of cotton fiber caused the Government of Uzbekistan (GoU) a loss of about US$1.5 billion between 1998 and 2001. This situation necessitated

[5] http://www.africanwater.org/aral.htm

[6] Other sources state this figure at more than 10 million people (http://kungrad.com/aral/book/word/).

[7] Narodnoe Slovo, 2005.

[8] UzReport.com, 2005.

[9] Egamberdi et al.

that both the GoU and the private sector substantially revive the domestic cotton-textile sector. At present, liberalized conditions favor cotton production and processing more than ever before, owing to stabilization of the legal framework for business, elimination of excessive external intervention into economic activity, simplification of licensing, registration and certification procedures, and a wide range of privileges (i.e. in taxation and import of auxiliary equipment, technological accessories and spare parts for industrial needs of the textile companies), preferences and guarantees for joint and foreign enterprises (i.e. in cotton fiber purchases). Recently, 94 pilot projects to update processing equipment were implemented. It is expected that these projects will lead to a gradual increase in the volume of domestic processing by up to 50% of the total volume of cotton fiber produced in the country, increase export value by US$1.17 billion and create about 46,000 new jobs.[10]

However, until now cotton fiber remained the main export commodity of Uzbekistan because the shift from export of cotton fiber to export of products with higher value added (cotton yarn, cotton fabrics, etc.) has not been as smooth and fast as anticipated. In order to maintain export revenues, the production of raw cotton and cotton fiber must be maintained at its current level, thus leaving little opportunity to lessen the dependence on cotton and to combat further ecological degradation, specifically in the Aral Sea basin.

Despite the many possible solutions suggested to rescue the Aral Sea and improve the environment and the living habitat, not much has changed since often the solutions have been seen in isolation. This study represents a comprehensive attempt to identify if agriculture (cropping area, water for irrigation, etc.) can be diversified from raw cotton and some progress towards improvement of ecological situation achieved without significant intervention from international donors and local governments.

The paper gives first an overview of the cotton sector in the Khorezm region, providing a comprehensive picture of the entire cotton value chain (CVC), including the cotton flows, actors involved and their interrelationships, costs of production, and income distribution along the cotton chain. Mapping the CVC advances the institutional, financial and economic analyses of all the stakeholders included under different scenarios.

[10] UzReport.com, 2005.

2. Study site and methodology

2.1. DESCRIPTION OF THE STUDY REGION

The research was conducted in 2004–2005 in the Khorezm region, located in the lower reaches of the Amu Darya in Northwest Uzbekistan. Khorezm is the smallest administrative region with 680,000 ha, bordering the southern edge of the ecologically degraded Aral Sea area. It has become one of the most problematic areas in terms of salinity, irrigation water availability and overall crop performance.[11] Only irrigated agriculture is possible and only on roughly 40% of the entire area of Khorezm. The agro-ecological conditions render Khorezm suitable for the production of annual, warm-season crops such as cotton.

Since Uzbekistan gained its independence in 1991, the area under cotton in Khorezm remained stable at around 100,000 ha, or around half of its total cropping area. Annual raw cotton output remained steady at 300,000 t except during 2000–2002 due to drought and during 2003 due to insect infestation. Given the average ginning outturn ratio of 30–33%, cotton fiber output is ca. 100,000 t. Cotton products (fiber, yarn, etc.) contribute up to 99% of the total regional export earnings.

In Khorezm cotton plantations were scattered throughout the region disregarding soil characteristics and soil fertility. Large areas qualified as marginal land (i.e. with low bonitet[12] levels) were persistently planted with cotton despite low returns to producers and continuing negative impacts on soil and the environment in general.

2.2. THE METHODOLOGICAL FRAMEWORK

The methodology for the value chain analysis included mapping[13] the CVC based on the functional and institutional analyses of the involved stakeholders. The functional analysis included the flows, both in physical and monetary values along the CVC, and the production stages[14] and provided the basis for developing the preliminary map. The institutional analysis described the role of all agents involved in the CVC that perform various functions, such as cotton farmers, gin plants, textile producers, etc. Furthermore, financial analysis was conducted to estimate the value added and efficiency indicators of the individual agents, as well as the entire CVC. Economic analysis

[11] Martius et al., 2004.
[12] Indicator for soil productivity used in Uzbekistan.
[13] Kaplinsky, R. and Morris, M., 2002.
[14] FAO, 2006a, b, c.

elaborated the economic accounts corresponding to the activities of the agents and policy implications, and also provided the cost breakdown technique for construction of the chains. This approach allowed also for the investigation of some scenarios aimed at mitigating the dependence on cotton while maintaining income both to the state and the farmers; and assessing ecological impacts of reforms in the cotton sector.

TABLE 1. Summary of survey methods and sample size.

Survey method	**Target group**	**Status in the CVC**	**Sample/population size**
Formal survey: stratified random sampling	Cotton growing farmers	Direct actor	99/7449
Formal survey, observation, case studies	Gin plants	Direct actor	10/10
Formal survey, observation, case studies, purposive sampling	Textile companies	Direct actor	13/26
Informal survey, secondary sources	Other agents/institutes involved in the cotton value chain: Khorezm Agriculture and Water Management Office, directors and engineers of the processing units, representatives of Machine Tractor Parks, bio laboratories,[15] fuel, and fertilizer distributing outlets, mini banks, farmers associations, commodity exchange, UzStandart Agency, Customs and Tax offices	Indirect actors	About 20/n.a.

<TFN>n.a. = not available.

[15] Biolaboratories are organizations providing services to farmers in Uzbekistan. One such service is breeding “good” insects for use in the fields as an alternative to chemicals and pesticides.

Several data collection methods originating from formal and informal survey methods were used to generate the required information (Table 1). Semi-structured interviews with questionnaires were conducted with the main, or direct, actors of the CVC. After a preliminary data check for possible blanks, revisits occurred when necessary.

3. Findings

3.1. GENERIC DESCRIPTION OF THE CVC IN KHOREZM

In its simplest form (Figure 1) the CVC consisted of cotton growing farms, gin plants or cotton refining plants, textile enterprises, and oil extraction plants, all of which were identified as the direct actors of the CVC. The flows of cotton products along the chain started with raw cotton coming from the farmers to the gin plants. Cotton fiber from the gin plants flowed to the textile enterprises and to a larger extent was exported. Cottonseed partly flowed back to the farmers as seeding material for the next agricultural season and partly to the oil extraction plant. Cotton oil and cottonseed meal and cake from the oil extraction plant were basically purchased by the population or partly exported to the neighboring countries. And finally textile products from textile producers were consumed within the region, or partly exported. The peculiarity of the CVC in Uzbekistan was the presence of the intermediate storage and distribution outlet, the "Cotton Terminal" (Figure 1).

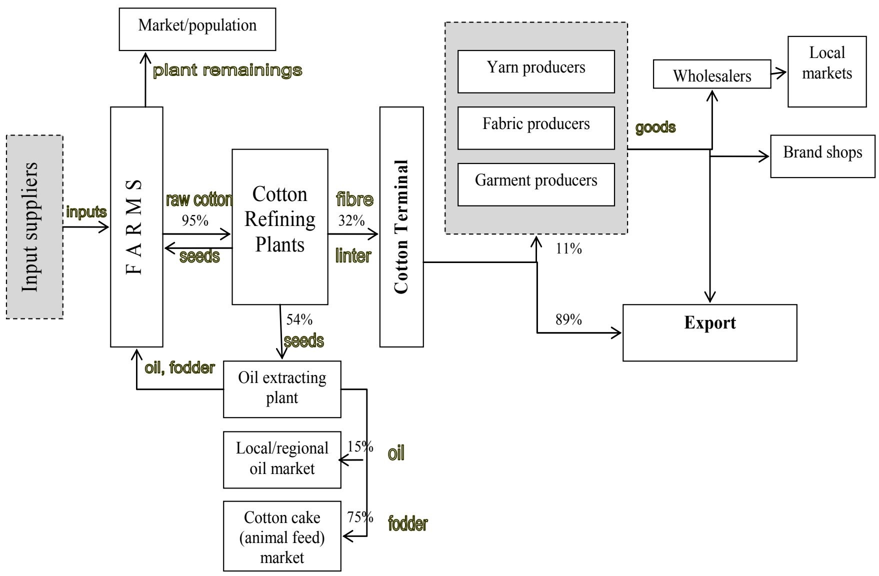

Figure 1. The CVC in the Khorezm region showing the direct actors and cotton products' flows for the period 2004–2005.

The two main cotton products were cotton fiber and cottonseed. Cotton fiber and linter were used to produce yarn, various fabrics (knitted, calico, etc.), absorbent cotton wool and others. Cottonseed was used to produce cotton oil, margarine, soap and also cotton cake and husk, an important animal feed in the region. Waste from the gin plants and oil extraction plants could be turned into spirits, insulation material, paints, varnish, etc. Leaves were a source of organic acids. Stems, besides being cheap fire-wood, were used in the preparation of coarse paper varieties, such as cardboard. One ton of raw cotton could yield on average 3,000 m of fabric, 100 kg of cotton oil, and 200–250 kg of cotton cake.[16]

3.2. DIRECT ACTORS OF THE CVC

Agricultural producers. The agricultural sector was the first link in the CVC. Although three types of agricultural producers existed in the Khorezm region during the survey (rural households – *dekhqans*,[17] private farms and *shirkats*[18]), raw cotton was grown by *shirkats* and private farms only. After the complete dissolution of the *shirkat* farm type in early 2006, private farms became the sole producers of the principal state target crop – cotton. Private farms contributed about 111,000 t, or 39% of the total raw cotton output of the Khorezm region in 2004 (Table 2), and about 223,000 t (77%) in 2005. In 2006 100% of raw cotton was produced on private farms.

TABLE 2. Raw cotton area and output by agricultural producers of the Khorezm region.

	Raw cotton area, ha		Raw cotton output, tons	
	2004	2005	2004	2005
Shirkats	66917	24165	175747	60203.2
Private farms	42874	85436	111407	223046.8
Khorezm total	109791	109601	287154	283250

Source: OblStat data, 2006

Cotton in the different regions of Uzbekistan was cultivated in the same way, with exceptions in leaching activities and cotton varieties. Cultivation practices included a wide range of activities, starting with land preparation and extending all the way to harvesting and transportation of raw cotton to the gin plants. Each cotton cultivation activity had associated costs, such as

[16] Ter-Avanesyan, 1973.

[17] A peasant or individual whose livelihood to a large extent depended on personal subsidiary plots and rural subsistence-type activities.

[18] Uzbek for a large-scale agricultural cooperative established from *kolkhoz* or *sovkhoz* on a share-holding basis.

machinery, labor and inputs. Agricultural producers interrelated closely with the gin plants, which accepted virtually all the raw cotton for further processing. The main problems of cotton farming according to the producers surveyed were the lack of agricultural machinery; limited irrigation water; poor soil characteristics (salinity and low fertility); improper crop rotation systems; and intense control over cotton farming by the state. Problems in the legal aspects of cotton farming were ranked last, which proves that legal training of farmers, as well as the awareness of their rights, was still very low in Uzbekistan. Other problems listed by the farmers concerned financial aspects, like delayed payments for output, low procurement prices, difficulty in accessing farmers' bank accounts, etc.

Gin plants. The ginning industry was the intermediary between producers and the first step in the processing of raw cotton. They accepted raw cotton, processed it into cotton fiber and prepared high-quality cottonseed stock. The ginning industry in Khorezm and Uzbekistan was governed by the semi governmental SJSC ("UzPakhtaSanoat"). It was established in 2001 as part of the de-monopolization and privatization reforms in the cotton ginning sector, and embraced 172 joint stock companies, 7 limited liability companies and 1 joint venture. It was mandated to (1) conduct systematic monitoring of the domestic and world cotton markets and sales opportunities and identify the most demanded cotton varieties; (2) render assistance to the regional branches and gin plants for the implementation of market reforms, production of competitive products, modernization of facilities, adoption of new technologies, and attraction of local and foreign investments; (3) assist in the distribution of cottonseed; (4) supervise the quality and quantity control of procured raw cotton and produced cotton fiber according to the state standard norms; and (5) prepare cotton products accounting balances together with the Ministry of Economy and the regional branches of "UzPakhtaSanoat", which is represented in each administrative region and responsible for a network of gin plants.

Gin plants in Khorezm procured raw cotton from farmers and processed it into cotton fiber. The raw cotton procurement included the in-take of the raw cotton, a quality check and pre-treatment (drying and cleaning), and transportation to the gin plants. Raw cotton processing/ginning was comprised of drying and cleaning, ginning and an additional cleaning of the fiber with subsequent pressing of fiber into bales.[19]

The cotton fiber was either exported or used domestically by the enterprises of the local textile industry. In 2005 cotton fiber export in Khorezm reached 89%, and the remaining 11% was utilized by local spinning,

[19] One cotton fiber bale in Uzbekistan is in the range of 210–220 kg.

weaving, and clothing factories. The Khorezm ginning sector can process around 426,000 t of raw cotton and produce 142,000 t of cotton fiber. However, gin plants in Khorezm worked in 2005 at around 70% of this maximum capacity and only 299,000 t of raw cotton were processed (Table 3).

The ginning sector of Khorezm showed rather poor performance, as evidenced by the average outturn ratio of 30–33%, with a solvency factor of 1.2, which was lower than the allowed minimum level rate[20] of 1.25; the low profitability of assets at 2%, which also was below the allowed lowest level of 5%; and the worn out equipment which dated back to the 1970–1980s. Problems mentioned by the gin plants were that, despite modernization attempts undertaken by the GoU and the regional state authorities, the ginning sector of the Khorezm region faced some factors hindering its further development. The process of modernization of the gin plants was slow and required considerable financial investment. The major issue was the outdated equipment, which caused poor ginning compared to international standards. However, in order to improve productivity and quality, new ginning equipment alone would not be sufficient, since gins operating at higher speeds had to be accompanied by a streamlining of the whole handling system, from storage in the fields to the way cotton was transported to the gins.[21]

Textile enterprises. The enterprises of “UzbekEngilSanoat”, part of the light industry sector of Uzbekistan, processed almost 255,000 t of cotton fiber annually. Domestic processing of the cotton fiber has been increasing gradually and it is expected to reach about half of the total potential output in the near future as a result of the dynamic development of the textile industry based on a stable inflow of direct foreign investment. With the purpose of further development of this industrial sector, the GoU planned to modernize and reconstruct existing enterprises and to establish new facilities by attracting additional investment, including FDI.

In 2005, 26 textile enterprises existed in the Khorezm region, some in the form of a joint stock company with Government participation (25% of shares), some as joint stock companies with the foreign partners, and the remainder as completely private companies (these were the numerous and small scale textile producers) and completely foreign owned companies. The first joint ventures appeared after independence; however, the majority of the joint ventures as well as the private companies were organized after 2000. At the time this research was conducted, only half of the 26 textile

[20] Based on data from De-monopolization Committee and according to the Resolution No. 1469 from 14.04.2005 of the Committee on economic failure of enterprises, attached to the Ministry of Economics of Uzbekistan.

[21] Cotton Outlook, 2005.

enterprises had been operating in Khorezm (Table 3). In total textile producers could process around 20,000 t of cotton fiber, twice as much as the

TABLE 3. Overview of the direct actors of the CVC in Khorezm for 2005.

	10 gin plants	26 textile enterprises	1 oil extraction plant
Type of company	SJSC: State share – 51% Workers share – 7% Free sale – 42%	Joint stock company JV Foreign owned company	Foreign company (Swiss corp)
Year established	End 19th–20th 1970s	1980s 2000s 1992	Before independence
Production	1. Raw cotton processing (t) 2. Cotton fiber (t) 3. Cottonseed (t) 4. Linter (t) 5. Mote (t) 6. Waste (t)	1. Cotton fiber (linter) processing (t) 2. Yarn (t) 3. Calico (thousand m^2) 4. Knitted garments 5. Mattress cotton (t) 6. Absorbent cotton (t)	1. Cotton oil (t) 2. Cottonseed meal (cakes) (t) 3. Laundry soap (t)
Designed capacity per year	1. 426,500 2. 142,204	1. 18,095 (5,000) 2. 15,310 3. 8,769 4. 3,360 5. 2,400	1. 37,440 2. 117,300 3. 13,152
Capacities in 2005	1. 298,819 2. 98,174 3. 138,998 4. 7,386 5. 4,248 6. 15,523	1. 6,962 (1,200) 2. 7,103 3. 6,032 4. 5. 1,077 6. 600	1. 21,258 2. 55,407 3. 6,333
Utilization of capacity	About 70%	1. 38% (24%) 2. 46% 3. 69% 4. 40% 5. 32% 6. 25%	1. 56% 2. 47% 3. 48%
Status	Low profit	Low profit; some currently not operating; some bankrupt	Profitable
Orientation of output	2. Export 89%	2. Export 90% 4. Export 80% 5. Export 80% 6. Export 100%	1. Export 2% 2. Export 9%

textile enterprises managed to buy via the commodity exchange,[22] utilizing thus only about 50% of their maximum capacities.

The main output of the textile enterprises of Khorezm were yarn, coarse cotton woven and non-woven fabrics, knitted fabrics and ready made garments (basically knitwear), and mattress and absorbent cotton (used for medical purposes). All producers operating in the realm of the textile industry in Khorezm experienced certain problems and obstacles to stable operation and further development. Some (mostly local textile companies) mentioned insufficient circulating assets to make the business run. Some (usually joint ventures) were not able to settle all amounts due to creditors. Some were able to produce, but did not have access to the main input – cotton fiber.[23]

The amount of cotton fiber left for domestic processing did not allow for a full utilization (refer to the Table 3) of their capacities and did not even cover half of the demand of the local textile producers for cotton fiber. Insufficient cotton fiber supply caused low cotton yarn output, which was also exported. Scarcity of fiber and yarn caused low output by the subsequent textile producers. Thus the capacities of the whole textile sector were highly underutilized, resulting in very low returns, longer payoff time for investments, larger interest payments (for expansion of the credit repayment period), etc. Many textile producers (mainly joint ventures), which imported equipment (not necessarily new) at the expense of huge credits went bankrupt without even having started their operations. Instead, the domestic textile product market was saturated with low quality textiles from China, or with better quality but higher priced textiles from Turkey. Textile products produced locally did meet quality standards and requirements of the local population and were priced affordably, but mostly exported to Russia (knitwear), Turkey (yarn) and other countries.

Oil extraction plant. Uzbekistan's oil extracting industry, with all oil extraction plants throughout the country, used to be owned and operated by the Joint Stock Association "Uzmaslojirtabakprom," which consisted of the former state extraction and refining facilities. In the last years, however, 4

[22] Since 2005–2006 cotton fiber for domestic use by textile producers was marketed only via commodity exchange and on conditions of a 100% prepayment and of availability of up to date equipment; both conditions were hard to be fulfilled by the local textile companies, which had lack of circulating assets and had a very limited scope for fast renovations and re-equipment.

[23] Currently, cotton fiber for domestic use by textile producers is marketed only via commodity exchange and on conditions of 100% prepayment and availability of up-to-date equipment; both conditions are difficult to fulfill for local textile companies, which lack circulating assets and have very limited modernization capabilities.

out of 19 oil extraction plants were privatized by foreign investors, one being the Urgench oil extraction plant in the Khorezm region.

The Urgench oil extraction plant changed its organizational structure from state to joint stock ownership in 1994; in 2003, it was partly privatized, but the State reserved 25% of joint stock value, and the remaining stocks were distributed among other shareholders.

In 2005, the Urgench oil extraction plant processed 128,700 t of cottonseed and produced 21,300 t of cotton crude oil, which was made into 18,600 t of refined edible oil, 6,300 t of laundry soap, 70 t of drying oil, and 55,400 t of cottonseed meal and cake. Some of the products were exported, mainly to the neighboring CIS countries, including 600 t of cotton oil and 5,300 t cottonseed meal and cake.

3.3. SCENARIO SIMULATION IN KHOREZM

A major objective of this study was to analyze the option of a complete utilization of the present textile capacities, without additional investments or state support and compare the 2005 export revenues from the CVC with less raw cotton production, less cotton area and less negative impact of cotton production on the environment. The export performance of the CVC in 2005 was 89% of the total fiber output, whereas 11% was processed domestically. This *baseline scenario* was compared to four other scenarios (Table 4). These scenarios were simulated to assess the potential impact and benefits from development of the CVC. The general assumption was to maintain the level of the CVC export revenues from 2005 provided (1) the full utilization of textile processing capacities present in the Khorezm region, which were roughly estimated at 20,000 t of cotton fiber per year; (2) increased export of textile products which have higher value and which create higher value added within the region than cotton fiber alone.

TABLE 4. Description of simulated scenarios.

Scenario	Description
Baseline scenario	CVC performance of 2005
Scenario 1	Export of **100% cotton fiber**, improved management, faster circulation of assets in the ginning sector
Scenario 2	Export of **71% cotton fiber** and **all cotton yarn** produced
Scenario 3	Export of **65% cotton fiber** and **all fabrics** produced
Scenario 4	Export of **32% cotton fiber** and **all garments (T-shirts)** produced

Results showed that development, upgrading and streamlining of the CVC in Khorezm would allow for a decrease in raw cotton production, cotton plantations, irrigation water use and amount of state budgetary resources used to subsidize raw cotton production. Improvement and better management of the ginning sector alone could allow for the reduction of 18,000 ha of cotton plantations, 136 million cubic meters of water for irrigation and about US$4 million in explicit subsidies compared to the baseline outcomes (Table 5, scenario 1).

TABLE 5. Results of simulated scenarios.

	Export revenue, billion UZS	Required raw cotton, thousand tons	Required cotton area, thousand ha	Reduction in cotton area, thousand ha	Reduction in cotton area, %	Rough irrigation water requirements, mio m3	Explicit subsidies to agriculture, million USD
Baseline	97.615	287	110	0	0	824	20
Scenario 1	97.615	239	92	18	17	688	16
Scenario 2	97.615	207	79	30	28	596	14
Scenario 3	97.615	173	67	43	39	499	12
Scenario 4	97.615	89	34	76	69	257	6

Because of price differentials between the different cotton products, enlarging the involvement of the local textile enterprises to the processing of cotton fiber into cotton yarn has a potential to earn the same regional export revenues but with a reduction of 30,000 ha of cotton, 228 million cubic meters of irrigation water and about US$6 million of explicit subsidies (Table 5, scenario 2). The best case scenario (Table 5, scenario 4) considering textile enterprises of Khorezm being engaged in further processing of cotton fiber into ready made garments, could decrease the main critical inputs for raw cotton production by more than two thirds, or by about 76,000 ha (or 69% of the total cotton area in use in 2005 and which was considered in the baseline scenario), 567 million cubic meters of irrigation water and about US$14 million of subsidies.

It should be mentioned that, along with the reduction in raw cotton production, the oil extracting industry in Khorezm would be affected (less raw cotton produced means less cottonseed for oil extraction) and would have to lower its production levels. Production of edible cotton oil would be reduced by up to 70% under different scenarios. However, this should not represent a problem, because other types of vegetable oil (sunflower seed oil, for example) are available and can be used as substitutes, which are healthier both for people and the environment.

4. Discussion and conclusions

The rather low current performance indicators of the textile sector of the CVC in the Khorezm region, evidenced by the low shares in total value added or export revenues, should not lead one to underestimate the potential of the CVC. As shown, increased local fiber processing could have significant positive effects. The development of the textile sector in particular would increase the integration of the CVC with the rest of the economy, earn higher export revenues, and create higher value added. Moreover, it could maintain the actual export revenues and probably output values with less raw cotton required. Thus there are options to achieve an improvement of the ecological situation without significant intervention from the international donor community and local governments and with no adverse effect on economic performance of the CVC. On a country level these initiatives were expected to increase local processing of cotton fiber by a further 230,000–250,000 t annually. According to some estimations, export of textile products instead of cotton fiber would lead to a two-fold increase of currency inflow to the country (in case of yarn and fabric exports) and an above four-fold increase in the export of ready made garments.[24]

In order to combine the economic and ecological demands it would be better to intensify cotton growing on those lands suitable and effective for cotton and instead abandon cotton production on marginal land as previously postulated.[25] Marginal land was estimated at about 20% of the total cultivated area.[26] A decrease in cotton area and a concurrent shift to use the land unsuitable for cotton for alternative crops, or establishing completely different land uses would create a greater potential to support ongoing attempts to prevent or at least lessen further degradation of the ecological situation in the region.

Raw cotton production on marginal land is economically inefficient and degrades the natural resource bases such as the soil even more. Such areas could be diverted from raw cotton to less intensive and less expensive land use systems, such as tree plantations,[27] 20 year projections for which show that they are more profitable than cotton production on marginal land.[28] Another alternative use of the land formerly cropped with cotton would be planting forage crops or establishing pastures for livestock.

[24] Namozov, 2005.
[25] Martius et al., 2004.
[26] Mueller, 2006.
[27] Khamzina et al., 2006.
[28] Lamers et al., 2007.

Furthermore, as cotton is highly subsidized by the state, decreased raw cotton production would also allow the state to save significant budget shares that would otherwise be pumped into underperforming cotton cultivation. These savings could be alternatively used for introducing and developing the production of vegetable oil or other more profitable enterprises. Some investments would be needed to shift the local oil extraction industry from producing cotton oil to producing sunflower seed oil, since a decreased raw cotton production would lead to some extent to a reduction in cotton oil production. Although oil consumption habits of the local population would have to change as well, sunflower seed oil seems promising in terms of being accepted by people[29] and in terms of opening up additional working places not only in oil extraction industry, but also in sunflower farming.

The study showed also that even given the present endowment of the CVC there were some changes towards a more environmentally friendly production pattern. The cotton farmers underlined that they readily shifted from applying chemical pesticides and fungicides for plant protection to the use of biological methods of plant protection, such as the “good insects” bred by biolaboratories and scattered in the region. One third of the surveyed farmers reported cooperation with biolaboratories vs. one fifth reporting pesticide application. Farmers seemed to prefer plant protection with biological methods because it was much cheaper, required no machinery (only the relatively cheap labor of biolaboratory staff) and was environmentally friendly.

A major constraint of the CVC in Uzbekistan is the performance of the operating chain. Following independence, a general institutional failure set in due to weak backward and forward linkage mechanisms. This failure, combined with a lack of coordination and mutual consultation on the part of stakeholders, hindered development of the chain. To increase the performance of the CVC and strengthen its competitiveness, both in terms of economics and environmental protection, certain challenges have to be faced and combated today in order to be prepared for the future. One key constraint represents the restricted access to top quality cotton fiber and high prices faced by the Uzbek textile producers. Moreover, the high tax burden and the unstable financial situation of textile enterprises impede further development of the CVC. The third challenge is the outdated technology used for the production of cotton fiber and textile products. As a result of the relatively high import dependency of ready-made garments and knitted wear on raw material, interim goods and accessories, local textile producers have to bear high costs associated with their imports and the high

[29] Bobojonov et al., 2008.

customs duties. Other problems include lack of alignment with global fashion trends, Uzbekistan's relatively low credit rating in comparison with other competing countries, and the low level of cooperation between Uzbekistan's banks and textile enterprises.[30]

There are several short and long-term options for improvement of the CVC, often associated with appropriate, focused and transparent legislation combined with proper implementation and enforcement. On a broader scale and from a long-term perspective, a system of financial incentives and manufacturing integration among the producers along the CVC could be introduced.[31] Substantial foreign investment can be attracted to support the production of high quality interim goods for textile manufacturing and the acquisition of chemicals, dyes, and accessories. Furthermore, a reduction or abolition of customs duties must be considered for those interim goods, accessories, and spare parts that are not feasible to produce domestically. It is advisable to reduce the tax burden on various actors of the CVC (via application of the mechanism of VAT exemption for example). The government could support the textile sector by developing a public relations campaign, like "Made in Uzbekistan," targeting both domestic and foreign markets to generate a favorable image of Uzbek textile products, especially for cotton goods and by attracting the major multinational clothing manufacturers, like Levi Strauss and others, to establish apparel production.[31]

Most important in the meantime, however, is to try to tie all the actors of the CVC (and mainly the textile companies) into one cotton value chain, so that supply meets demand in every part of the chain so that all parties involved have a stable working environment and the added value created in the cotton-textile sector is the highest possible in the given circumstances. Cotton fiber should be sold to domestic consumers not through the auction system but through daily exchange trades, which will create similar conditions for access to cotton fiber for local textile producers and provide incentives for enterprises to update their facilities rapidly.

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[30] UNDP in Uzbekistan, 2006.
[31] UNDP in Uzbekistan, 2006.

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Cotton factory in Khorezm, Uzbekistan.

STRATEGIC ENVIRONMENTAL ASSESSMENT IN THE REPUBLIC OF BELARUS: STATUS, PROBLEMS AND PERSPECTIVES

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Abstract. The article describes the application of a completely new tool, Strategic Environmental Assessment (SEA), in the Republic of Belarus. On the basis of previous experience obtained during participation in the international pilot projects, the authors analyze advantages of the strategic environmental assessment application, current problems in the process of SEA implementation, the experience of the methodological recommendation document development and possible ways of including SEA in a planning process. The application of the SEA approach is especially important today in the context of the Republic of Belarus' future inclusion in the Kyiv Protocol on Strategic Environmental Assessment and the Convention on Environmental Impact Assessment in a trans-boundary context.

Keywords: Strategic environmental assessment, strategic documents, methodological recommendations, strategic planning, environmental impact assessment, state environmental review

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1. Introduction

Strategic Environmental Assessment (SEA) is a tool that makes it possible to evaluate long-term environmental consequences of a developing strategic decision and make any "high-level" document (strategy, forecast or program) more "ecological" by introducing environmental aspects already at the document's development stage (Protocol on Strategic Environmental Assessment, 2003).

SEA is used by many countries worldwide. Some Belarusian specialists believe that such a tool has existed and has been applied in Belarus for a long time. As an example, they point to the territorially complex scheme of the environmental protection of the Mogilev district developed in 1998. They also address territorially complex schemes that are being developed in the evolution of spatial development plans for Belarusian cities.

It should be mentioned, however, that according to Belarusian legislation, these schemes belong to special city development and planning projects. SEA, however, is applied to the documents of strategic level, not project level. This is the main difference between the SEA program report (as well as other strategic documents) and territorially complex schemes of environmental protection.

The application and integration of SEA into a strategic level decision-making process is obligatory for the states that have ratified the Convention on Environmental Impact Assessment in a trans-boundary context and the Protocol of the European Economic Commission on Strategic Environmental Assessment to this Convention (Kyiv Protocol). It is in the Kyiv Protocol that SEA objects are pointed out, the general procedure for carrying out SEA is determined and some international requirements for SEA tool application are described (Protocol on Strategic Environmental Assessment, 2003).

The Republic of Belarus became a part of the Convention on Environmental Impact Assessment in a trans-boundary context on February 8, 2006. One of the current tasks on the national agenda is based on this Convention, as well as on the National Environmental Action Plan for 2010. The task is to join the Kyiv Protocol to SEA. Another task is to assess the expertise, laws and administrative potential required for high-quality SEA application.

Today thanks to a range of seminars, trainings and pilot projects, Belarusian ecology specialists are beginning to understand that tools like SEA allow them to take into account environmental protection requirements during the planning process itself. This also allows them to reduce time spent on the agreement procedure, i.e. for revisions of strategic documents after their correction by interested state organizations. Thus, it makes the strategic document more "ecological" and more "economical".

2. Legislative framework and existing practice

The Republic of Belarus has good experience in conducting environmental assessment of project decisions in different fields of the national economy. At the same time, it is difficult to apply such an assessment to strategies, forecasts and programs. Such documents suggest only general directions of socio-economic development and, as a rule, lack specific action plans. Thus, a SEA tool and its application is practically a new approach to the planning process.

The first analysis of a current station in the field of SEA in Belarus took place in April 2004 with the presentation of future changes in legislative and normative bases and prioritized directions of the SEA Protocol implementation.

In August 2007, the Ministry of Nature approved the Strategy of Capacity Development in the Field of Strategic Environmental Assessment in the Republic of Belarus for a 5-year period ending in 2012. In preparing the strategy, the results of the assessment of national requirements in the field of capacity building of SEA in Belarus for 2004 were used. This document stated mid-term and long-term goals and objectives for capacity development on SEA. The strategy was aimed at improving the mechanism for evaluating environmental and human health protection measures over the course of the decision making process on different levels of state management.

The current planning system in the Republic of Belarus is characterized by the fact that different projects on national, regional and local levels are the results of national, regional or local program realization, as well as the realization of socio-economic, sectoral or territorial development forecasts. The development of the strategic documents of socio-economic, sectoral and territorial development in Belarus is carried out by the responsible ministries and local organizations of state management. These organizations develop most of the strategies, programs and forecasts, which are the basis for SEA application in Belarus.

In Belarus there is no full legislation system for SEA, but some of its elements are represented in the following legislation:

- The Law “On the Environmental Protection”
- The Law “On the State Environmental Review”
- The Direction “On the Order of Conducting Environmental Impact Assessments”
- The Directive “On State Environmental Review”

Officially the Convention on Environmental Impact Assessment in a trans-boundary context and Aarhus Convention on access to environmental information were approved and signed. Thus, these documents are included in the legislative base of the country. Furthermore, the legislation about the natural resource conservation of Belarus includes many normative acts on separate components of the environment. The experts also use corresponding bylaws and technical normative acts, such as building and sanitary norms and rules, among others.

We shall pay special attention to the Law “On State Environmental Review”. It is this legislative document that includes the points concerning SEA. According to the law, the concepts, programs (including investment) and schemes of territorial and sectoral socio-economic development are the objects of the State Environmental Review (article 6). Today the Ministry of Nature is working to develop two documents concerning SEA – “Methodical Recommendations on the Order of Carrying out Strategic Environmental Assessment in Belarus” and “The Guidance on SEA Application”.

3. Problems concerning the application of SEA in Belarus

Previous experience with applying SEA to strategic document development and adoption was gained by conducting two pilot projects: SEA of the National Program of Tourism Development and SEA of the Concept of Sustainable Development. The projects, sponsored by the Regional Environmental Centre in Budapest, were carried out in an effort to provide international assistance to Belarus. The authors’ participation in these projects allows us to predict some problems that can appear while implementing SEA in Belarus.

In the Republic of Belarus planning is carried out by many federal and local management organizations. However, very few specialists working with the sector and investment programs, as well as other strategic documents, know about the existence of SEA. This is one of the biggest obstacles to the effective implementation of SEA in the planning process.

Moreover, planners are not interested in incorporating SEA into their documents, as they do not realize the advantages which might be gained by implementing SEA in the early planning stages. Most strategic document planners mistakenly connect SEA with environmental impact assessment. They do not differentiate these tools at all.

In light of the legislative controls mentioned above, Spatial Development Plans and schemes of territorial development are subjects of State Environmental Review on the regular basis. On the contrary, programs of socio-economic development and sectoral development are subject to review only in specific cases. Such disparity between legislative requirements and practice has its roots in the absence of effective implementation and enforcement mechanisms for environmental review of programs.

It should also be mentioned that the procedure of state environmental review has nothing to do with the requirements of Kyiv Protocol on SEA. We should emphasize that, as a rule, environmental assessment of the materials of spatial development plans and sector programs is carried out in the coordination stage, and not in the process of development.

At the coordination stage, the Ministry of Nature and the Ministry of Health can indicate some overlooked impacts and environmental problems and return the document for follow-up or revision as needed. Most of the time, however, to change the documents in their final stage is very difficult. It might only be done for the sake of involved institutions. Otherwise the process of development of strategic documents would be unreasonably postponed.

Moreover, for such strategic documents such as investment and sector programs environmental assessment is not obligatory and is not carried out systematically. In the Republic of Belarus, a well-established and legislatively regulated planning procedure is absent. Furthermore, deadlines for the development of the most important strategic documents are not set. The procedure for consideration and confirmation of such documents is absolutely free. Thus, there is a serious problem of how to include the SEA stages into the planning process.

According to current legislation, only the planner can decide whether to consult the Ministry of Nature and Ministry of Health concerning the developed document. The planner also decides if there is a need to address the ministries to receive the analysis and assessment of possible environmental consequences of the project as well as the need to take them into account in the strategic documents.

4. Methodological recommendations for document development

Preliminary evaluation has shown that our country's membership in the Kyiv Protocol will require the adoption of a number of legislative documents on behalf of our government, including fixing the SEA procedure at the level of a normative legal act. The creation of this document is possible only after the preliminary approbation of SEA procedure in real strategic planning. The obtained results have to be applied first in the recommendation document and after that in the juridical act.

The authors' participation as experts in SEA pilot projects, through the accumulation of experience in this field, made it possible to develop a recommendation document "Methodological Recommendations on the Order of Carrying out Strategic Environmental Assessment in Belarus".

The document represents the authors' vision of possible fields of SEA application. It also represents the methods and procedures of implementation of SEA in different strategic documents. The order in which various steps of SEA should be implemented according to peculiarities of planning process is also addressed, i.e. stages of development of a strategic document and the main requirements for the SEA report. The authors also give recommendations for the most optimal integration of SEA into the planning process.

One of the most important problems that appeared during the development of the methodological recommendations was the choice of terminology, since the terminology used in international documents differs from that which is accepted in the Republic.

The objects of SEA throughout the world are policies, plans and programs. We decided that according to the law "On State Forecasting …" strategies, forecasts, and programs are considered to be strategic documents in Belarus. Such strategic documents as policies, which are considered to be SEA objects, are not represented in the current Belarusian legislation and, therefore, are not considered a SEA object in the Republic. There are, however, commonalities in terminology, as both the Kyiv Protocol and all Republic documents consider the fields which have the greatest effects on the environment, including agriculture, water, forest economy, industry, energy, tourism, telecommunications, waste management, planning and building up residential areas to be the objects of SEA (The Law of the Republic of Belarus, 1998).

Much attention is paid to the procedure of creating a group of experts on SEA. In order to conduct SEA effectively in the future, it is recommended to create an information data base of experts on environmental assessment who can participate in the SEA process (an association of freelance experts). The planner of the strategic document is responsible for organizing and carrying out SEA in collaboration with one or more of these experts.

In the process of making the recommendations, the issue of defining the role and place of the Ministry of Natural Resources and Environmental Protection and Ministry of Health raised a lot of discussion between the authors. In our opinion, they must have coordinating functions. These functions include coordination of experts' technical work, methodological assistance provided to the community when necessary, participation in consultations with the experts of the SEA group, community and developers of the strategic document, and assessment of the effectiveness of the SEA while coordinating the strategic document.

During the determination of the order of conducting strategic environmental assessment the authors tried to compare possible steps for carrying out SEA and appropriate stages of developing the strategic document.

The mechanism of involvement of public relations (PR) is treated as a separate issue. Public participation is obligatory, first of all, from the requirements of international documents of SEA, and, secondly, through the constitutional civil right to public participation in the decision of general problems (Convention on Access to Information, 2001).

At the stage of developing the concept of the strategic document there are detailed recommendations on creating an expert group, which must include a PR expert and a representative of the working group which develops the strategic document. It is during this period that the forms of public participation are determined. For this purpose we can organize a workshop consisting of the expert group, the planner and the public to consider proposals about sharing information and gathering feedback from the public.

According to the international practice of carrying out SEA, the methodological recommendations emphasize that the group of experts not only sets different environmental and social objectives but also analyses the extent to which the developed strategic document takes into account the outlined problems. Special attention in the Guidance is devoted to the preparation of the report on SEA, which must include recommendations suggested by the group of experts and taken by the developers, as well as suggestions by the expert group that were not taken into account by the developers.

5. Recommendations for SEA implementation in Belarus

1. The development and implementation of the SEA approach will be possible only after creating an appropriate legislative framework and approval of the methodological base.
2. Coordination with the Ministry of Nature on the technical work project for the carrying out SEA might produce a very positive effect. This way, we may discuss the plan of consultations, including those with the Ministry of Nature and other interested organizations. It would also be beneficial if the Ministry of Nature assessed the report on SEA.
3. We should look for closer cooperation with the planner group. Before the actual work begins, it would be preferable to develop a step-by-step approach for the mutual discussion of the results of the document development. The method of taking into account recommendations of the SEA expert group should also be discussed.
4. Plan active dialogue and discussion between different participants in the SEA process (not only with the planners).
5. Ask the organization-planner to sign a document that would permit the SEA group to discuss intermediate results of the work (based on papers of the planner and recommendations of the SEA group) in public; this would allow public participation during the SEA process and not only in the final SEA report.

Encourage interested organizations (different NGOs, according to the Aarhus Convention) to participate in consultations, with the aim of better implementing SEA specialist recommendations through the organizations.

7. As early as the first stage of planning, the question of how the information received as a result of carrying out the SEA will be taken into account in revisions or improvements to the strategic document should be addressed.
8. Screening of the specialists in the SEA expert group must be realized with regard to specification of the estimated document in relation to the probable negative impact for the various fields. It would be beneficial to encourage participation of sociologists, medical professionals, lawyers, economists and other specialists who can contribute their knowledge to the discussion of environmental protection.
9. It is necessary to set up a center or some other organization which would gather the scientific potential of our republic as well as some data base (an association of freelance experts) containing information about experts in the field of SEA.
10. The inclusion of SEA into the programs of institutions of higher education would help to promote SEA as well.

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MONITORING URBAN GREENERY FOR SUSTAINABLE URBAN MANAGEMENT

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Abstract. Environmental problems undermine sustainable development of cities. Environmental protection – and the protection of plants, in particular – is a compulsory element for sustainable urban management. Urban greenery is thus a key natural resource for a city; besides, vegetation has vast health and aesthetic significance for people. Plants are able to reduce many pollutants in the environment, and they create specific microclimates by decreasing wind, noise, and solar irradiation. On the other hand, urban environmental effects on different aspects of plants' vital functions modify the state of vegetation vastly. These modifications touch individual physiological and morphological parameters, longevity, growth, and evolution, and increase the tolerance of urban plants to different pressures such as drought, cold or vermin. It is obvious that developing a system of monitoring urban greenery is an essential task for any city. This system is able to give information related to the current state of urban vegetation and forecast various situations. In this paper, some problems in monitoring urban vegetation are described. Research presented includes developing a state framework and associated program "Assessment of the ecological state of Tashkent". Urban plants, including dominating species of trees, shrubs, and lawn grasses, were the subjects of this study. Reducing linear growth, inhibiting significant accumulation of heavy metals, and increasing photosynthetic efficiency coefficients were revealed for urban green spaces in different sites in Tashkent under moderately increasing levels of air, water, and soil pollution. Moreover, it has been noticed that new trees, shrubs, and grasses are often lost due to inappropriate or poor care and because of overuse. It is clear that any city will develop sustainably with the adoption of natural resource conservation practices in the city's area, as the natural resources assure economic growth and high quality of life for the population.

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1. Introduction

Sustainable development means economic stability and social health against a background of environmental well-being. The rate of urbanization is rising. In the near future, the majority of Earth's population will live in cities. Unfortunately, cities are usually sources of environmental issues. Perhaps this tendency is because of the pursuit of economic development and industrialization without an ecologically positive orientation in cities and suburbs.

Any city can be regarded as a special human and natural system. Urban environmental quality is determined by many factors. These factors can be divided into three groups: (1) negative effects (chemical pollutants, waste, noise, vibration, and electromagnetic contamination); (2) compensative factors (urban greenery, ponds and streams in the city); and (3) facultative factors (city planning and building up of urban area, roads and highways). All of them must be regulated by a system of urban management to mitigate the impact of negative factors and increase the efficiency and positive effects of compensative and facultative factors.

Plants are an important factor in the development of urban environmental quality. The key role of urban greenery is not biomass production or oxygen synthesis, but rather the regulation of urban air composition and the creation of a favorable microclimate in the city. On one hand, plants are able to remove chemical pollutants and solid particles from the air, as well as reduce noise and wind, thereby improving the overall health and aesthetics of the urban environment. On the other hand, plants depend heavily on the environment in which they grow. Many plants are extremely sensitive to air pollution, acid-forming gases or heavy metals in particular. Air pollutants have serious negative effects on vegetation, depressing growth and evolution, suppressing photosynthesis, disturbing metabolism, and causing degradation and loss (Figure 1).

Tashkent was regarded one of the greenest Central Asian cities for many years. Targeted tree planting in the city has been performed since the beginning of the twentieth century (Kuzmichev and Pechenicyn, 1979). Unfortunately, recent investigations have indicated a decrease in both green areas and diversity of flora used. Increased air pollution levels in the city are one of the main reasons for the loss of green space and plant diversity. As a result, development of an urban greenery monitoring system is an urgent task in Tashkent.

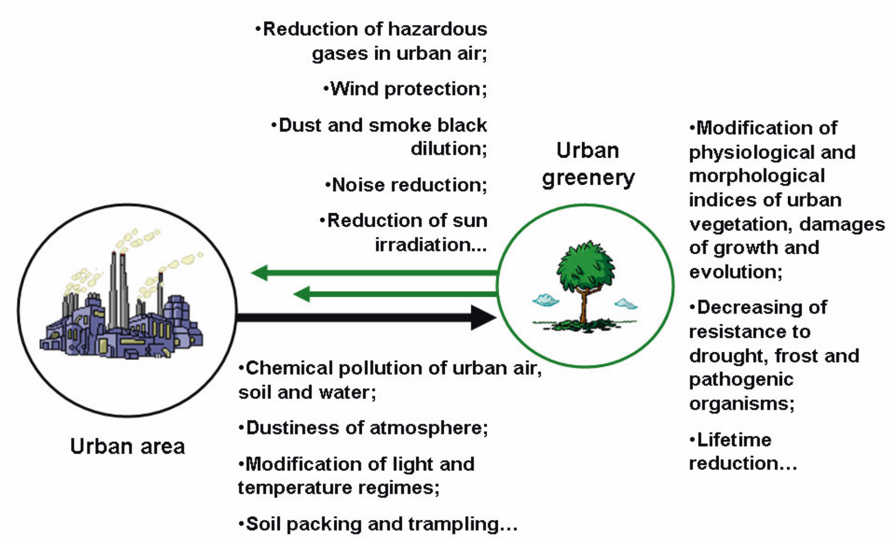

Figure 1. Relationship between urban area and urban greenery.

In addition, responses of plants and/or the accumulation of toxins in plant tissues can serve as good indicators of air quality. The potential to expand the basis for gathering environmental quality samples is very important, as there are only 12 observation posts of the State Meteorological Service in the city of Tashkent, which is more than 400 km^2. Three meteorological parameters (temperature, wind and moisture) and concentrations of 4–9 air pollutants are measured currently at these observation posts. This quantity of data is insufficient to control and manage air quality in such a large city as Tashkent. It is necessary to enrich and extend physicochemical methods of air quality control using biological methods. They must be mutually complementary. Bio-monitoring of air quality using plants will not only allow direct assessment of risk from exposure, but it is also less expensive and more efficient.

Investigations of the state of urban greenery and development of the bio-monitoring system for urban air have been performed since 2003 in the framework of the State research program "Evaluation of ecological state of Tashkent city." One of the aims of this research is the development of recommendations for sustainable management in Tashkent on the basis of environmental data. Selection of sensitive and correct indices for registration and evaluation of the air pollution impact on urban plants is one of the important points of this program. Some results of this research related to passive bio-monitoring of the air quality in Tashkent are presented in this paper.

2. Materials and methods

Investigations were carried out in the city of Tashkent, which is situated in Central Asia. There are continental climate conditions here; summer is usually long (from mid May to September), very hot, and practically without precipitation.

Leaves of lawn grasses, as well as plane (Platanus orientalis), sophora (Sophora japonica), Circassian walnut (Juglans regia), elm (Ulmus pumila L.), oak (Quercus robur), Juniper (Juniperus turkestanica), Crimean pine (Pinus Pallasiana Lamb), ailanthus (Ailantus altissima), and other trees, were chosen as subjects of this inquiry. Leaves of the trees were sampled from the lower tier (about 2.5–3 m) in the month of September each year during the period 2003–2005 (before first autumn rains). In addition, heavy metal concentrations in the grasses were measured in 2003–2005 in 30 points throughout the city in the time of the most intensive vegetation (May). All vegetation samples were washed and air-dried at ambient laboratory temperature. Heavy metal concentrations and chlorophyll content in the leaves were measured. Collected leaves of plane trees were washed with distilled water, which was then filtered and dried. Quantitative and qualitative analysis of dust taken from those leaves was performed; dust weight from 1 m^2 of leaf surface and Pb, Cd, Zn, Cu levels in the dust was measured. These results were compared with long-term observations of the State meteorological service on air pollution in points of vegetation sampling.

The methods of sampling, analysis and data evaluation are described in standard manuals.

3. Results and discussion

One of the research aims in this study was to select the most appropriate indices for monitoring urban greenery. Various indices of vegetation state were tested to find the best indicators of air pollution levels in the city. Linear growth, chlorophyll concentration, photosynthetic efficiency coefficient, weight of dust on the leaf surface, and concentrations of heavy metals in the plant tissues were investigated. Certain results are presented in this paper.

3.1. LINEAR GROWTH

It is well known that coniferous trees are highly sensitive to air pollution (Goryshina, 1989, 1991). Linear growth is a key indicator of the tree state for the last year. Performed investigations have indicated that “linear growth value" of coniferous trees can be used as an effective indicator for bio-monitoring purposes. Obtained results have shown that yearly linear growth of Crimean Pine in Tashkent is much less than nursery-grown trees of the same species. The 5–8 year-old nursery-grown trees had 3–6 m in height and yearly linear growth of 0.6–0.8 m. Mean linear growth of pine trees in the city varied from 0.14 to 0.19 m high and had maximal linear growth of 0.31–0.44 m. In addition, the city trees had fewer needles and tops of several needles on the city pines were brown.

Air pollution and dust loading are major reasons for the worsening condition of the pines in Tashkent. Thus, linear growth of the coniferous trees can be used as suitable index of integrated air pollution in passive bio-monitoring, but it is necessary to take into consideration water and soil quality in city points under observation.

3.2. CHLOROPHYLL CONCENTRATION

The photosynthetic apparatus of plant cells is modified by a number of environmental factors, including air pollution (Goryshina, 1991; Mulgrew and Wiliams, 2000). Chlorophyll concentration is one of indicators of the condition of this apparatus. Chlorophyll content in leaves of trees and grasses in 12 city points were measured. Data collected indicate that the dynamics of chlorophyll "a" and "b" concentrations in leaves of plane trees correlate with the same characters in leaves of grasses from the same observation points; correlation coefficient is 0.89 (Figure 2).

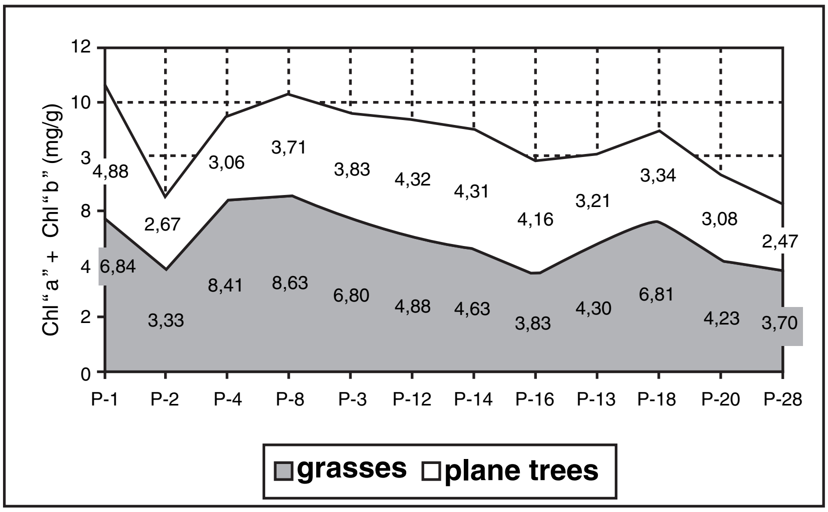

Figure 2. Chlorophyll concentration in leaves of plane trees and grasses, Tashkent, P – observation posts of the State Meteorological Service.

Steps were taken to find the relationship between Chl-content in leaves and TAPI (Total Air Pollution Index). Obtained results do not confirm direct correlation between these characters now. This is due to the fact that the condition of the photosynthetic apparatus state depends heavily on many other factors such as light, soil and water conditions (Mulgrew and Wiliams, 2000). Evidently, it is necessary to match city points with similar conditions in order to control specifically for the impact of air pollution on urban plants. Thus, chlorophyll concentration is not an efficient measure for a passive bio-monitoring in non-uniform urban areas. However, it can be recommended as a sensitive and objective indicator for active bio-monitoring studies of air quality using transplanted plants raised in the same conditions.

3.3. RESPIRATION AND PHOTOSYNTHESIS

Respiration and photosynthesis are the most important physiological processes in plant life. They are standard indicators for a plant state assessment. It was interesting to investigate photosynthetic activity and respiratory rates of certain plants from different sites in Tashkent. Collected data indicated that gaseous exchange intensity of vegetation is too ecologically dependent to allow accurate interpretation. A far more objective index of vegetation state for bio-monitoring purposes is the Photosynthetic Efficiency Coefficient (PEC), which is the ratio of production to consumption of oxygen by a plant. This coefficient indicates the physiological state of the plant in specific environmental conditions more accurately. Moreover, the PEC describes two of the most important physiological processes in plant life simultaneously. It is important to note that the PEC is species dependent. Background (control) PECs for 14 species of urban trees have been determined. It is proposed to assess the environment quality and integrated air pollution in an urban area on the basis of PEC fluctuation.

For example, the PECs of four kinds of urban trees (plane, maple, ash and sophora) were measured in different city sites (Table 1).

TABLE 1. Photosynthetic efficiency coefficients for leaves of certain trees, Tashkent, May–June 2004.

Trees	City-points		
	1	2	3
Plane (*Platanus orientalis*)	4.3 ± 0.20	3.7 ± 0.15	2.4 ± 0.12
Maple (*Acer campestre*)	2.5 ± 0.11	1.9 ± 0.06	1.8 ± 0.11
Ash (*Fraxinus americana*)	2.4 ± 0.09	1.4 ± 0.08	1.3 ± 0.07
Sophora (*Sophora japonica*)	1.8 ± 0.11	1.4 ± 0.10	1.1 ± 0.05

Those trees grow in three different environmental conditions: (1) a background city point with comparatively clean air; (2) a broad highway with good ventilation; (3) a narrow road with bad ventilation in a built-up area. Obtained results are presented in Table 1. Quality of biotopes in the city points under investigation was evaluated on the basis of performed measurements. These sites were arranged in order of worsening environmental quality: 1 > 2 > 3. With the necessary background and/or control values of the coefficients of the same plants species, the PEC can be used in bio-monitoring of urban air pollution.

3.4. DUST ACCUMULATION ON LEAF SURFACES

The dust content in the air is usually high in Tashkent (in fact, the long-term annual average aerial dust concentration is 0.165 mg of particulate matter per 1 m^3 of Tashkent air, although the average daily permissible concentration of particulate matter in the air of populated areas is just 0.05 mg/m^3 (National Report, 2006). A lot of air particulate pollutants collect on the leaf surfaces of plants during vegetation. Dust forms sediments on leaves, blocks photosynthesis, respiration, and transpiration, and can cause physical damage in plants (Goryshina, 1991; Trombulak and Frissel, 2000; Kovacs, 1992). Due to the accumulation of pollutants on leaf surfaces, leaves of urban greenery can be used for a quantitative and qualitative assessment of particulate matter content in urban air.

Dust accumulation on the leaves of plane trees in the end of vegetation was measured in 12 points in Tashkent. The mean dust sedimentation accumulated on leaf surfaces of the trees in Tashkent (autumn, 2003 and 2004) was 2.2 g/m^2; in industrial areas – 2.25; on main roadways – 2.37; and in residential areas – 1.27. The maximum quantity of dust was 4.58 g/m^2, and the minimum was 0.66 g/m^2. Evidently, the maximal dust sedimentation is observed in city-points situated in industrial zones and near highways.

The correlation between dust accumulation on the leaf surface and dust concentrations in the air is not established for all city points. Particle deposition on leaf surfaces may be affected by a variety of factors, including particle size and mass, wind velocity, leaf orientation, size, moisture level and surface characteristics (Goryshina, 1991). Our experiments revealed that the above mentioned relationship is observed only in areas with weak ventilation or in areas which are shielded from winds from other areas (Figure 3). A direct correlation between particulate matter concentration in the air and dust accumulation on leaf surfaces was observed only in five investigated city points. These points can serve as base stations of the monitoring system for dry deposition in Tashkent in the future. Realized experiments show weak correlation between dust sedimentation on leaf surfaces and chlorophyll levels in the leaf tissues. We believe this weak correlation is due to the vastly different conditions in which the plane trees in this study grew (widely varying watering, lighting, soil quality, etc.). At the same time, a direct relationship between the quantity of dust on the leaf surface and ChlA/ChlB ratio in leaf tissue was discovered in our investigation, the correlation coefficient of which was about 0.91.

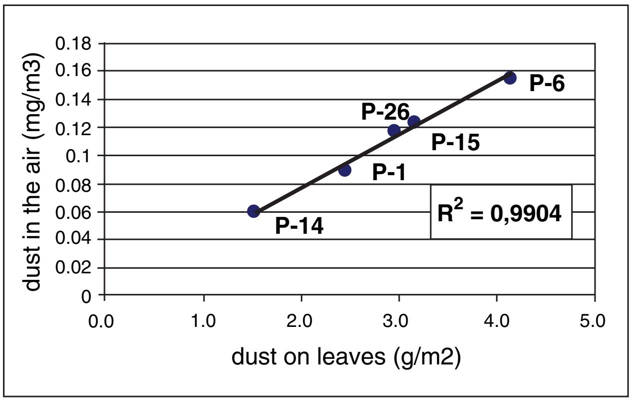

Figure 3. Correlation between dust accumulations on leaf surfaces and annual average dust concentrations in the air.

3.5. HEAVY METAL CONTENT

It is known that many plant species can be used to detect aerial heavy metal pollution because of their bio-accumulative features (Trombulak and Frissel, 2000; Kovacs, 1992). The significance of foliar accumulation and translocation of metal pollutants in the air was demonstrated experimentally (Harrison and Chirgawi, 1989); the foliar route was found to be of similar importance to the soil-root pathway (Goryshina, 1991). In connection, concentrations of Pb, Cu, Zn and Cd in leaf tissues and dust from leaf surfaces were measured in the Tashkent area. Results are in Table 2. Obtained data have shown that grass leaf tissues accumulate a greater quantity of heavy metals than leaves of trees from the same city point. At the same time, it has revealed that vegetation in north and north-east parts of Tashkent contains a lot more heavy metal in the leaves. Among the heavy metal pollutants, Zn contributed most to the heavy metal content in the air, leaf tissues and dust in all points of Tashkent.

Additionally, comparative analysis of heavy metal content was made in leaf tissues of urban greenery and trees/grasses from the Chatcal National Park area. Sampling in Tashkent was in a background city-point with comparatively clean air. It has revealed that heavy metal contents in Tashkent plants are much higher than concentrations of the metals in plants from the territory of the National Park, in which the regional station of background environmental monitoring is situated. These data indicate increased heavy metal content in the air and soil of Tashkent. It is necessary to notice that operating by "mean" or "average" metal concentration in plant tissues is incorrect. Concentrations of heavy metals in individual plant species should be used for monitoring purposes.

TABLE 2. Heavy metal contents in leaf tissues and dust from leaf surface Tashkent, August–September 2003–2004.

		(mg/kg dry wt.)		
		Mean	Maximum	Minimum
Pb	Dust from leaf surface	148.69	299.89	53.01
	Trees	3.32	6.37	1.37
	Grasses	15.62	33.43	0.21
Cd	Dust from leaf surface	2.66	3.88	1.09
	Trees	0.18	0.39	0.07
	Grasses	0.28	0.38	0.06
Cu	Dust from leaf surface	65.74	151.07	54.01
	Trees	9.3	15.02	4.81
	Grasses	12.67	23.53	6.92
Zn	Dust from leaf surface	288.32	556.92	213.06
	Trees	23.35	30	16.34
	Grasses	52.9	78.79	39.52

4. Conclusions

Thus, recent investigations indicate deterioration of vegetation in many sites in Tashkent. Rising pollution of the urban environment, extreme pressure from recreational activities, improper selection of planting areas, and inadequate care for urban greenery has resulted in a reduction of urban green areas and assortment of decorative plants; an increase in air pollution levels; the loss of decorative features of urban plants; and an increase in the cost of renewal of urban greenery and recovery of population health. Deterioration of the condition of urban vegetation causes economic, ecological and social damage, thereby contributing to the instability of city development.

Elaboration of a sustainable city management plan must be based on collection and analysis of valid data on the urban air, soil, water, vegetation condition, and population health; and on the basis of information related to sources of negative impacts on these components of the urban environment.

Monitoring and protection of urban greenery is an essential element of sustainable urban management. Therefore, continuous control for vegetation conditions and work on scientific-based planting of trees and grasses in city areas is necessary. Linear growth, photosynthetic efficiency coefficient and heavy metal concentrations in plant tissues are proposed as the most appropriate, efficient and objective indices for urban greenery monitoring.

An electronic database "Resistant and Sensitive to Air Pollution Plants of Arid Zones" was created in the National University of Uzbekistan under the framework of a State Research Program (Grant A-7.238). This database contains the following:

- Information related to resistance to air pollution of decorative plants suitable for planting in urban areas in arid regions
- Recommendations for scientific-based planting of trees and grasses in urban areas
- Information about plants sensitive to air pollution – indicators which can be used in arid zones
- Methods and guides for biological monitoring of urban air quality using plants

This database can become the theoretical background for intelligent planting of trees and grasses in the Tashkent area and establishment of biological monitoring of urban air quality in the area using plants. It should be understood that any city will develop sustainably with the assumption of natural resource conservation in this area, as natural resources assure economic prosperity and high quality of life for people. Environmental issues in cities undermine the sustainable economy, and cities with low standards of living are more vulnerable to social and political instability. Thus, environmental protection and the protection of plants in particular is necessary to improve urban management. Economic development and environmental protection can and must be combined.

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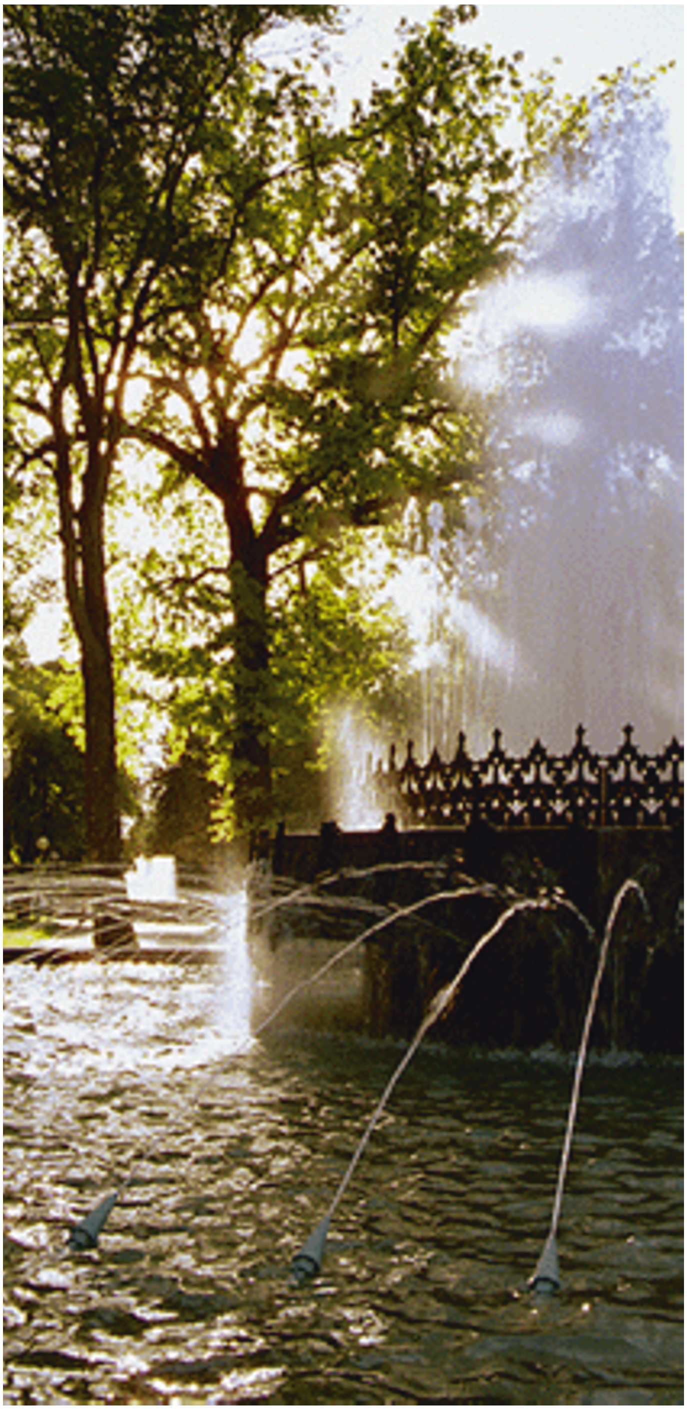

Fountain in Tashkent.