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NEW APPROACHES TO WATER MANAGEMENT IN CENTRAL ASIA

Proceedings of
A Joint UNU-ICARDA
International Workshop
held in Aleppo, Syria
6-11 November 2000

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Edited by
Zafar Adeel

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Preface

The issues of water availability are closely linked to human welfare and health as well as food and economic security. The problems related to water resource management in Central Asia are particularly complex and are intertwined with social, economic, political and technical issues. Some major drivers behind these problems include the limited quantity of water available, pollution of available water, salinization of soils, and land degradation.

This workshop was an important step forward in fully understanding the nature of problems faced in the Central Asian region. It is apparent that water resources must be viewed strategically at the river basin level. Appropriate management of demand and supply of water resources as well as maintenance of existing irrigation systems is critical for long-term sustainability.

Another important contribution of this workshop is to prioritize the areas of water issues for the Central Asian region as well as the West Asian and North African (WANA) region. Some of the new approaches recommended by the workshop include the recently-developed approaches of water harvesting, supplemental irrigation and deficit irrigation. Some of these technologies have been quite successfully tested at pilot scale and now require a broader implementation. Similarly, a number of approaches are available for safe and productive use of recycled water in agricultural applications. In conjunction with recycled water application, emphasis has to be given to development of appropriate water treatment technologies that are suited to local conditions.

I would also like to extend my appreciation to ICARDA for co-organizing and hosting the workshop. The excellent logistical arrangements and the productive contributions to the workshop made it a very positive experience for all the participants. I hope that this lays the foundation for a long-term collaboration of UNU with ICARDA on themes of critical importance to the dry areas.

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Foreword

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Jointly organized by the United Nations University (UNU), Japan, and the International Center for Agricultural Research in the Dry Areas (ICARDA), with support from UNESCO, the workshop on "New Approaches to Water Management in Central Asia" was held at ICARDA to address the agricultural research needs of Central Asia, with focus on water.

Over 35 researchers from four Central Asian countries (Uzbekistan, Kyrgyzstan, Kazakstan, Tajikistan), Japan, Syria, Iran, Niger, Kuwait, Saudi Arabia, France, Russia, China, and Pakistan participated in the workshop, in addition to those from UNU and ICARDA.

The Central and West Asia and North Africa (CWANA) region is the largest continuous strip of dryland in the world, and constitutes the regional geographic mandate of ICARDA. The increasing water scarcity in the region is a disturbing challenge, which can only be met through increased knowledge. ICARDA's water research program in the dry areas, in collaboration with national agricultural research systems (NARSs) and advanced research institutions (ARIs), aims at a sustainable improvement of water productivity under conditions of increasing water scarcity. The Center follows two strategies in its collaborative research to increase dryland water-use efficiency: the use of cutting-edge technology in the development of high-yielding crop varieties that use less water, and agro-management techniques to minimize abuse and misuse of water in dry areas. The latter include water harvesting and the use of modern technologies, such as modeling, remote sensing, and GIS, to detect available water; and technologies that make marginal-quality water usable for agriculture.

Amongst the ARIs with which ICARDA collaborates is the United Nations University (UNU) in Tokyo, Japan. This Workshop was one of the several collaborative activities undertaken by the two institutions. The workshop focused on critical issues related to water management in Central Asia. Presentations over the three days included country presentations by representatives from Uzbekistan, Kazakstan, Kyrgyzstan, and Tajikistan, and commissioned presentations from experts on Central Asia, WANA, China, and Niger. Presentations were also made by scientists from

ICARDA, UNU, and other advanced institutes on issues related to water management in the region.

Discussions on the critical issues, the priorities, the approaches, and the innovations in water management were the basis for developing a framework for joint project proposals between ICARDA and UNU to translate the vision of the workshop into action.

This volume contains the presentations made at the workshop. I hope it will serve as a useful reference source and guide for those interested in addressing the problems of water scarcity in the dry areas, particularly in Central Asia.

Prof. Dr. Adel El-Beltagy
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Workshop Overview

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The most vulnerable areas in any ecosystem are the ones at its periphery. Most of the land erosion, degradation of soil quality, loss of biodiversity, and eventual loss of productivity occurs in these marginal – but high-priority – lands. This is particularly true in "Dry Areas", those comprising arid, semi-arid and dry sub-humid regions. Sustainable and integrated management strategies in these dry areas are needed for protection, preservation and reclamation or rehabilitation in these fragile ecosystems and natural resources contained therein. Such strategies are closely linked to human development and quality of life in these marginal lands.

This workshop primarily focused on the challenges faced in the Central Asian region and explored new strategies to cope with them. Some case studies from other regions were also included for the sake of comparison. Water management was used a focal point of discussion on integrated approaches for land management. Some workshop participants highlighted the status of water management in Central Asia. This provided the backdrop in which to discuss innovative approaches to overcome these challenges. A number of promising approaches for water management were described; these include rainwater harvesting techniques, aquifer recharge methods, and applications involving re-use of municipal sewage or wastewater. In conjunction with recycled water application, development of cheaper water treatment technologies suited to local conditions was also recommended. Generally speaking, water productivity can be significantly improved through these recently-developed approaches and in some situations very significant benefits can be reaped through enhancement of indigenous and traditional management approaches.

It is obvious that development of integrated approaches is critical to minimizing land degradation and the related societal and economic impacts. There is a need to promote actions for building and strengthening existing institutional capacities for regional, national and basin-level agencies to effectively address and integrate cross-sectoral aspects. Defining such integrated approaches is a complex job and the outcome would vary from region to region. It was, therefore, also recognized during the workshop that the regional priorities for Central Asia and West Asia/North Africa are somewhat distinct. This distinction should be appropriately reflected in the scientifically-based policy guidelines to be developed for dry areas. The long- and short-term evaluation of environmental and socio-economic impacts of such policies has to be a critical component of the policy development process. It is anticipated that the recommendations identified in this document can be of use in sustainable management of the limited and precious resources in Dry Areas.

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Systems View of the Water Management in Central Asia

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Interdisciplinary and Multicriterial Objectives

The largest closed area in the world is situated in the middle of Asian continent, and a good part of it is called Central Asia. The latter is a region where high mountains and arid low-lying plains are not only neighbors but they constitute a system with water playing the key role in it. It is not simply a natural system, but ecological, political, social and economic one as well. Therefore, most of the problems in the system require an interdisciplinary approach. Besides, majority of problems have different objectives. These multicriterial problems cannot be solved to the satisfaction of all partners in a conflict (interest groups, social classes, nations, etc.), and a trade-off among the alternatives is a usual way of life. One has to deal with the systemic issues of mutidisciplinary and multicriterial character. In all this complexity water resources and their use have a key role.

The Principal Features of Central Asia

On the south of Central Asia, its border is very well defined by the high mountain systems of Tian-Shan, Pamir (both with the altitude of up to 7500 m a.s.l.), Alai, Kopetdag, and others. Virtually all available water resources of the region are formed in high mountains of the south. More north, at the foot of the mountains, one finds an excellent combination of good, fertile soils, generous sunshine, and river water coming down from the mountains. The maximum of then river water is mostly in summer, when the plants' water demand is the highest. It is the zone where the traditional irrigation existed for millennia, and this is the center of ancient civilizations.

To the north, there is no natural border for Central Asia. The vast arid plains, with the altitude mostly of 100-200 m above sea level and, in some places, even below the sea level, extend well to the north, that is towards the south of Siberia. The southern part of this vast area is known as Kyzylkum and Karakum Deserts. Within some limitations, one can say that the northern border of Central Asia extends to where the waters coming down from the mountains dissipate.

From the water resources point of view, one can observe three main zones in Central Asia: the high mountain zone of run-off formation, the zone of predominant irrigation developments, mostly at the foothills, and the zone of run-off dissipation situated on the plains. The total area of Central Asia is about 1.5 million km3, more exact figure depends on where to draw the northern border of the region in question.

Geographically, Central Asia is an area of few river basins extending north from the mountains to the deserts. In terms of run-off, it is one of the largest closed areas in the world. They are endorehic and arehic territories. The former means a territory with some run-off, but it goes down to depressions without giving any flow to outside the region, while on the latter territory the run-off is not produced almost at all.

The central, most important and clearly defined part of Central Asia is the basin of Aral Sea, that used to be the second lake in the world by its area. Aral Sea has only two tributaries, Amudarya and Syrdarya, while there is no any outgoing stream. There are also few smaller rivers going down to the north. Most of them used to be tributaries of Syrdarya and Amudarya during the periods of better climate. Due to the human activity (mostly the irrigation development) and the climatic oscillations, they dissipate at the foothills providing water for irrigation and do not reach Aral.

In terms of politics, under Central Asia one usually understands the territory of the former (until end-1991) Soviet Republics that belonged to the then USSR: The whole of Kirgizstan, Tadjikistan, Turkmenistan, and Uzbekistan, with the population of over 40 million, plus the southern part of Kazakhstan. Some parts of Afganistan and Iran (17% of the total of the basin) also belong to Amudarya River basin, but the involvement of these two countries in complex issues of water resources management is not yet on the agenda.

Water Resources of Central Asia

The figure of the total river run-off for Central Asia cited in a literature varies mostly between 110 and 120 km3 depending on the period chosen, the methodology to calculate the flow of temporary streams and the accuracy of the run-off measurements. Few rivers flowing down from Kopetdag Ridge within Turkmenistan (Murgab, Tedjen and Atrek) do not change noticeably the figure mentioned above.

The annual river run-off of the tributaries of Aral Sea at the foot of the mountains for a relatively stable period of 1930-1975 was 112 km^3 (Lvovitch, 1986).

Mean annual run-off of the rivers of the Aral Sea basin, 1930-1975, km^3:

Syrdarya	Amudarya	Chu & Talas	Zarafshan	Kashkadarya	Total
38.8	61.3	8.46	2.56	0.62	112

Irrigation is far the main user of water withdrawing for each of the four countries between 84% and 91% of their total run-off.
The groundwater resources of acceptable quality, which are not hydraulically connected with the river systems, are about 2.5 km^3/year (UNEP, 1993). Hence, the main source of water is the river run-off.

Additional resource, though of lower quality, is the irrigation return water. The volume of the return water is quite high depending largely on irrigation developments in the basin. For instance, the annual flow of Syrdarya River at the foothills of the mountains in 1930's contained 10% of the return water, but due to active hydraulic works in the basin by 1960's it carried in its total run-off up to 60% of the returned water (Rubinova, 1973). V.L.Shulz (1975), a leading hydrologist of Central Asia in the recent past, estimated for few major rivers, including Syrdarya, the share of irrigation returned water between 15 and 30% of the total run-off.

The per capita water resources for the total of four Central Asian countries (Kirgizstan, Tadjikistan, Turkmenistan, and Uzbekistan) is approximately 2800 m3 a year. It clearly places the region in the category of water deficient one. Adding up to this figure the return waters would slightly increase this index up to 3400 m3 per person a year, but still the region remains within the category of limited water resources. One should be reminded, however, that quite a number of countries with well developed irrigation belong to the same category.

One distinctive feature makes Central Asia different from the many other territories. In order to maintain the water level of Aral Sea, one has to give water to the Sea. The first half of the 20th century clearly demonstrated that to keep the water level of Aral more or less stable, one has to give to the Sea about 55 km^3 of water a year. With this consideration in mind, the per capita water resources of Central Asia come down to 1400 m^3 per person per year. From this point of view, Central Asia faces already now a severe water deficit. It would become ever more grave as long as the population would grow, while water resources would keep stable. It may lead to a serious social and political insecurity in the region.

Sandra Postel (1999) mentions a value of 1700 m3 per person as a world-wide critical index. She writes that as a nation's run-off per person drops below about 1700 m^3, food self-sufficiency for the country becomes difficult, if not impossible. Below this value, there is often not enough usable water to meet the demands of industries and cities and to grow enough food for the entire population while at the same time sustaining river flows for navigation, fisheries, and other functions. Countries in this situation then begin to import water indirectly, in the form of grain.

The four countries in question are quite different from the point of view of water resources availability and their use: the most rich with water resources are Tadjikistan and Kirgizstan while the main water users are Uzbekistan and Turkmenistan. Potentially, this geographic situation is a source of conflicts.

The Aral Sea problem

Aral Sea is situated in a very arid region with annual precipitation of about 100 mm. On the area between the plains and the mountains precipitation is between 400 and 500 mm, and in the mountains it exceeds in some points 2000 mm. The total amount of precipitation on the basin of Aral Sea is about 500 km^3 a year, and the run-off is about 110-120 km^3. Syrdarya and Amudarya at their mouths used to carry to Aral Sea about 55 km^3 a year. That was enough to maintain the oscillations of water level within 2-3 m during 1860-1960.

At the end of the 1950s the leadership of the USSR made a decision on an extensive development of irrigation in the Aral Sea Basin. It was believed that the irrigation may become the main remedy in solving many agricultural problems of the USSR. It was expected that the expansion of irrigation in Central Asia would bring the prosperity both for the region and to the USSR as a whole. It was clear to the water resources experts that one of the main side effects would be the deterioration, if not the disappearance, of the Aral Sea. However, that time it was not considered as an important issue.

Investments in the irrigation of Central Asia during 1960s-1980s were of the order of 50 billion dollars (The conversion rate between the Soviet Rouble and the US Dollar is very approximate). The area of irrigated lands in the Aral Sea basin has increased from 5 million to 7-8 million hectares. The consumption of water is excessive. Each hectare of cotton requires there about 17,000 m^3 a year, while the standard figure would be 8000 m^3. The new 3 million hectares for irrigation would mean eventually 51 km^3 of water a year not coming to Aral Sea, in addition to 55 km^3 traditionally taken. The approximate figure of 106 km^3 is what is used in the basin of Aral Sea and, hence, what the lake does not receive. It means that the river water have reached Aral only in the years with flow above average. The last figure is quite comparable with the volume of the flow of Syrdarya and Amudarya. Indeed, during 1990s some river water reached Aral in the water-abundant years. The gradual development of new irrigated lands meant a steady decrease in the inflow to the Lake and the deterioration of the Sea:

Year	Water level m a.s.l.	Area 000 km^2	Volume km^3	Salt content g/l
1960	53.3	67.9	1090	10.0
1970	51.6	60.4	970	11.1
1980	46.2	52.5	670	16.5
1990	39.0	38.0	300	29.0

Within 30 years (1960-1990) the water level of Aral Sea dropped down by 14.3 m. The volume decreased by 790 km^3 or 3.6 times, and the surface has shrunk by almost 30,000 km^2 or 1.8 times. The mean depth changed from 16.0 m to 7.9 m. By 1995 the water level dropped by 2 m more. The salinity of water in the lake reached the oceanic one, that is 35 g/l.

In 1988-1989 two parts of the lake, - the smaller northern part called Small Sea or Small Aral and the larger southern part called Big Sea or Big Aral divided completely. Some Syrdarya water goes predominantly to Smaller Sea, and its water level became more or less stable. The area of Big Sea keeps shrinking. Big and Small Seas are connected with a strait through which some excess water from the latter go to Big Sea.

The Large-Scale Water Transfers

Some estimates indicate that about 90% of water resources in Central Asia are already in use while the population keeps growing with the rate of 800-900 thousand a year. It is well known that there are two strategic solutions of a looming water crisis: to look for an additional water supply sources or to improve the methods of more efficient use of available water. The main strategy in the region was the former, but the surface water resources are practically exhausted and groundwater resources are very limited.

The only large-scale option to increase the availability of water resources was to take a part of water from the mighty rivers of Siberia flowing North and to transfer it by way of a system of water reservoirs, pumping stations and large, long canals to the South, that is to the North of Central Asia. The length of the main canal would be of the order of 2000 km with the water discharge of about 25-50 km^3 per year. The project would be very costly.

In 1960s – 1980s the projects of large-scale water transfers were quite popular in many countries. The world-wide experience, including that of Central Asia, has been put together in two books (Golubev and Biswas, 1979; Golubev and Biswas, 1985).

In the Soviet Union, the water transfer projects were considered as the main solution to the water deficit, with the expectations to increase the productivity of agriculture among other problems. The gains were obvious: new water would be a good combination with the lands to be irrigated. Besides, the indigenous population was growing in numbers creating the occupation problem. Rural people wanted to keep working on land, without migrating to the cities. Uzbecs and Tadjics in particular, they are very good to work in irrigation. In this way, the social problems, such as an employment would be also solved somehow.

Many research and design institutions have been working in the USSR on various aspects of the water transfers. They brought, however, the conclusions which contained both positive and negative features. The main drawbacks of the water transfers are as follows:

- Very high cost of the project and a high cost of a cubic meter of the transferred water;
- The environmental consequences would be many, some of them are presently unpredictable.
- There is no reliable methodology to integrate the environmental costs into the total costs.
- For economic reasons, by necessity, the main conveyance canal would be unlined. That would lead to the great losses of the transferred water and deterioration of its quality.
- At the best, the Siberian water would get to the lowest reaches of Syrdarya River, that is to the least productive lands within Central Asia. Then the Central Asian water currently used there would be withdrawn in the middle part of Syrdarya basin. It does not look like a solution for the whole of Central Asia. Redistribution of the Siberian water all over Central Asia would be also very costly and technically complicated.
- The removal of large part of water from Siberia south would bring serious ecological consequences. Some of them might be positive because, for instance, some bogs might get drier. At the same time, in total, the biological productivity of the Ob River system would be less than now.
- The redistribution of water among the states of Central Asia and the subjects of the USSR and, later, the Russian Federation, is a very difficult problem both legally and politically. Presently, it is difficult to imagine how this problem can be solved.

Concluding this discussion, one can say that the large-scale transfer of Siberian water to Central Asia is a very complex problem, difficult, if not impossible to be solved, from the political, economic, environmental, technical, juridical, etc., points of view. Besides, the indigenous Central Asian water is not efficiently used, and some good reserves can be found in a better water management, without making very costly constructions and not very well known consequences.

Improved Water Management

The water consumption in Central Asia is excessive in general and the effectiveness of water management remains to be improved. Perhaps, the main reason for the low efficiency is the lack of economic interest to save water. Of course it is a typical case in quite many regions of irrigation. In Central Asia, the efficiency of irrigation systems is between 55-65% due to a seepage from the distributing canals and a predominantly furrow method of watering. The main canals are mostly unlined. As have been said already, the large volumes of agricultural return water cause pronounced changes in the hydrological and geochemical regimes.

The actual water consumption of crops exceeds their necessary consumption by 150-200% (Glazovsky, 1990). One of the ways to cut the excessive water consumption is to cut planting such crops as rice for the reasons of water management efficiency, and other cereals for economic reasons. To stop irrigating 15% of the land of Central Asia being of the lowest productivity, would save about 20 km3 of water. The plantations of rice of low quality, but of a high water consumption, have already been reduced.

Improved efficiency of irrigation systems seems to be the main and the last reserve for Central Asia. It is expected that the presentations made at this Workshop and the ensuing discussion would update our common knowledge about a progress in efficient irrigation techniques.

Irrigation and environment

In the irrigated areas a new, ample network of the irrigation and drainage canals have been formed. The level of ground water has gone up drastically in many places due to the seepage causing widespread water-logging. There, the salinization of soils is also a major problem. Large losses of water are characteristic of all levels of the irrigation network Correspondingly, the vegetation and ecosystems change considerably creating lakes, ponds and bogs in the predominant landscape of deserts.

A characteristic feature of the agricultural part of Central Asia is large canals. The largest in Amudarya River basin are Karakum (11 km^3 a year), Amu-Bukhara (5.8 km^3) and Karshi (3.6 km^3). In Syrdarya River basin they are Large Fergana (3.4 km^3) and Yuzhno-Golodnostepsky (3.4 km^3). Many of these canals loose a lot of water due to the seepage. A good part of water filtering through the grounds comes out to the surface forming small and large lakes and ponds. The total area of such ponds in the basin of Aral Sea is over 7000 km^2. The largest two are Sarykamysh in the basin of Amydarya with the surface of about 3000 km^2 nd volume of 26 km^3, and Arnasai in the basin of Syrdarya (1800-2400 km^2 and, correspondingly, 12-20 km^3). These two lakes receive annually 4.5-5.0 and 2.1-2.3 km^3 of the return water correspondingly (Mikhailov and Gurov, 2000).

Geochemical Aspects of Water Management

The development of irrigation is associated with massive and pronounced changes in the chemical state of the environment. Under natural conditions, the soils of agricultural areas of Central Asia contain large amounts of salts in the vertical profile. When irrigation is introduced, new additional portions of water seep down through the soils profile dissolving the salts and making them to move in the artificial or natural drainage systems. Therefore, a massive irrigation development means also the change in the geochemical regime at a regional scale.

In Central Asia, the direction, intensity and composition of the salts transport have modified considerably. The expansion of irrigation has lead to the increase of the salts movement mostly with the drainage run-off. It has been calculated that the salts transport in the Aral Sea basin has increased about two times and is now up to 120 million tonnes a year (Glazovsky, 1990). During 30 years (1960-1990) of a remarkable irrigation development a huge amount of three billion tonnes of salts were moved within the basin. Of this volume, 60% have accumulated nearby, in local ecosystems, small new lakes and bogs, 27% have gone to the two large new lakes, Sarykamysh and Arnasai, mentioned above, and 13% reached Aral. Moreover, the transport of sodium, chlorine, sulfate and magnesium has increased much more than that of the other main ions like calcium or carbonate.

Wind erosion of the former bottom of the Aral Sea has increased greatly, 0.5 to 3.5 times, in different points around the lake. The salts transport goes along with it taking away between 1,000 and 10,000 t/km2 per annum. For the whole former lake bottom it comes to about 100 million tonnes a year.

Transport of salts with the drainage water, wind and groundwater together with the raise of the groundwater level leads to the progressive salinization of soils. Soils with a medium and high degree of salinization occupy from 35 to 80% of the irrigated areas in Central Asia. Water logging is another serious widespread problem. The land losses due to water management activities are of the order of 1 million hectares. In fact, when designing a new irrigation system, one has to build on a combination of water resources and the salts transport.

The environmental degradation, namely unacceptable drinking water quality, high salts contents in the air, and, possibly, large concentration of pesticides residues in the agricultural produce have made direct impacts on the state of human health in the Aral Sea basin. The worst situation is where the above factors make the most unfavorable combination, that is around Aral Sea, particularly in the lower reaches of Syrdarya and Amudarya.

The medical indicators there are astonishing. For instance, for a number of districts in the lower reaches of Syrdarya River the infant mortality is comparable with that of the least developed countries. The number of cancer cases in the lower reaches of Amudarya is 7 times the former USSR basin. Over 90% of the population there suffer from anaemia. It is 60 times more than the average for the former Soviet Union. There are many more indicators of the environmental crisis. One can say that the water level of Aral Sea is an index of the difficult social-economic situation in the whole region of Central Asia. The contribution to improve the state of

Aral Sea may be made indirectly, by means of actions in social-economic sphere.

Environment and Development

The development strategy for the region has been adopted about fifty years ago. It is obvious now that it was wrong. It has lead to the environmental catastrophe, maybe the largest in the world. The strategy has proved to unsustainable. A new development strategy for the region is urgently needed.

The most urgent problem is an expeditious improvement of the environment for the population, in particular in the areas close to Aral Sea. Major water conveying pipelines transporting water of acceptable quality have been built and many desalination stations have been put into the operation.

A comprehensive, long-term program of the land-and-water resources management should be one of the cornerstones of the strategy. It should contain such elements as dropping low productivity lands from irrigation, increase of efficiency of the irrigation systems, drastic reduction of water applied for a unit of cropland, diversification of crops and liquidation of the cotton monoculture, optimal use of fertilizers and pesticides, application of the integrated pest management systems.

However, the strategy must go well beyond the modern land-and-water management program. It should go to the roots of the catastrophe addressing principal social and economic problems such as population control, a balanced ratio between the demand and supply of cotton, an appropriate structure for crop and livestock production, development of the agricultural extension services, conversion of industry from the military production, and considerable improvement of the social amenities including education at all levels and reasonable medical services.

Much care should be devoted to cooperation among the nations of the region as the only basis for the lasting, sustainable development of the potentially rich territory of Central Asia.

International Issues of Water Management

Central Asia has quite high rate of population increase. The development of irrigation could not absorb the growing population, and unemployment is high. There is a danger of increased tensions among the neighbors. The national boundaries drawn in 1920s in some places do not adequately reflect the realities. Under these conditions, the management of a large, multinational natural system is not a simple task.

With the break up of the Soviet Union the water management situation in Central Asia have changed. In place of one large country, presently the five new countries have to operate in sharing the water resources mostly of just two rivers. Afganistan may come up as the sixth partner. Russia cannot be discounted as it is the source of large water resources relatively nearby.

Kyrgyzstan and Tadjikistan are the areas of predominant river run-off formation, with the water used for irrigation in the low-lying Uzbekistan, Turkmenistan and in the south of Kazakhstan. To smooth out the variations of river flow within a year, a number of water reservoirs have been built, including such large reservoirs as Toktogul in Kyrgyzstan and Nurek in Tadjikistan. These two countries do not have enough hydrocarbon natural resources as the main source of their energy production. The overall objective in water management of Kyrgyzstan and Tadjikistan is to release a good part of water from the reservoirs in winter season to produce energy while the low-lying countries, Uzbekistan in particular need water for irrigation during summer. Potentially, it is a conflict situation.

The Karakum Canal built in Turkmenistan during the last few decades takes more than 10 km^3 of water a year. Apparently, there is no way to reduce this withdrawal as the new settlements based in the area of the canal on the Amudarya water and situated in Turkmenistan have to be maintained.

The shores of the Aral Sea belong to Uzbekistan and Kazakhstan, but huge amount of water needed to maintain the water level of the lake comes mostly from the mountains and, hence, from the other countries.

All these and similar problems are a potential source of international conflicts. There is no way to solve these problems through conflicts. The mainstream way is the international cooperation in system-wide improvement of all aspects of water management on the long-term basis.

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Water Problems in Central Asia – Gigantomania Should be Replaced by Small Projects

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Introduction

Located in the temperate climatic zone, Central Asia undergoes very harsh continental conditions and all the area between the 50 and 30th parallels suffer to various degrees extremely cold winters and summer dryness.

Ten years ago, when the Soviet Asian Republics became independent, were put in open light the numerous environmental difficulties mainly linked to the misuse of water, ending in the so-called "Aral sea crisis".

A large part of the Aral sea basin is provided with surface water gathered from peripheral mountains, which amounts to some 120 km^3 per year (Létolle et Mainguet 1993), essentially concentrated in the major basins of Syr Darya and Amu Darya, to which are added the minor ones of Tedjen and Murghab in the South, and the Ili basin which feeds the Balkhash lake in Kazakhstan from the Chinese territory. In natural conditions, between 60 and 80 km^3 per year flowed to the Aral sea, which established a near-equilibrium situation for this endoreic lake. On the other hand, lake Balkhash received about 15 km^3 per year.

Due to heavy withdrawals for irrigation mainly since 1960, which take today almost 90 % of the river water, Aral receives presently only 5 to 10 km^3 of drainage water and Balkhash 5 km^3. The consequences often described are severe regression of the Aral lake by two thirds of its volume (and to a less extent, 20% of the Balkhash), with effects on the local water table, salinization and deflation on the shores and disappearance of the natural flora and fauna.

In the lower course of the rivers - for example Karakalpakstan on the lower course of Amu Daria - heavy irrigation produced salinization of soils, hydromorphism, and heavy pollution by salt, fertilizers and various chemicals, with subsequent deterioration of the quality of soils and of the underground aquifer (bacterial contamination and chemical toxicity) and impacts on crop productivity and the health of the inhabitants.

Even if many papers and reports have described all this in detail and some have proposed useful ideas about the solutions to overcome these negative effects, it appears unrealistic to consider the possibility to get the Aral Sea and Balkhash lake recover their previous state, essentially due to the fact that all withdrawn water will be in the future indispensible for agriculture, the products of which are food for the inhabitants and money revenue through export, at last for many decades to come.

Considering that the withdrawal of more than say, 70 km^3 of water is an irreversible need for agriculture, present problems should be discussed at three scales: interstate scale, regional scale and the scale of local water quality.

Allocation of water between the States

Under the soviet regime, water from the mountains was dispatched between the Republics through a centralized system located in Tashkent, which gave place in the last 1980's to a BVO basin organization giving some freedom to the users. Since independance, Kyrghyzstan and Tadjikistan possess now the upper courses of the main rivers, that is more than 75% of the resource in surface water of the ASB, and can store it in a series of giant reservoirs in the higher parts of the basins. These States, poor in coal, gas and oil resources, rely on hydroelectricity, which they wish to keep for winter heating, whereas the needs of Kazakhstan and Uzbekistan are greater in summer for irrigation. The multi-state agreement signed in 1996 is practically unapplied, due to commercial disputes between upper and lower countries (the last one occurred in may 2000 between Tadjikistan, Uzbekistan and South Kazakhstan, when the quota for spring irrigation for the "Hunger Steppe" cotton fields was not delivered). Unexpected high floods of the Syr Darya in 1997 and poor monitoring of the dams in Ferghana led to reject several cubic kilometers of good water in the Arnasai depression, used as waste reservoir, from where it is impossible to get it back.

Very precise planning for a rational distribution have been brought up particularly by USAID to the governements concerned, specially for the dispatching of the water from the big Toktogul reservoir in Kyrghystan (10 km^3 capacity) and on the lower course of Syr Darya. Compensation for water and hydroelectricity from

Kyrghystan in fuel, coal and alimentary products have been planned. Tadjikistan is also concerned for the Ferghana valley. However, the countries in conflict do not yet entirely agree on the terms of the proposed agreement.

An agreement exists for years between Uzbekistan and Turkmenistan for the supply of water from the Uzbek part of the Amu Darya to Turkmenistan. About half of the total flow of the river is used to supply the big South Karakum (ex-Lenin) canal and the Turkmen part of the delta. Difficulties will arise from Turkmenistan, as this country is presently extending the Karakum canal beyond Kazandjik to the eastern coast of the Caspian sea. Other problems will arise when Afghanistan will ask for its share part of the Amu Darya water, along the course of which this State has a long frontier with Uzbekistan and Tadjikistan; presently the withdrawals by Afghanistan are very modest.

Another problem is presently arising between Kazakhstan and China as the latter country has begun to increase its water withdrawals from the Irtysh and the Ili rivers, without any new agreement between the two States.

All these countries project to extend their agricultural production, for local use as well as for exportation, and it is to fear that many arguments will occur in the next future, without any easy solution.

Rational Use for Water at a Regional Scale

Most of the water is used for irrigation. Agriculture is the first water consumer with 40 to 50 % for industrial agrosystems, specially cotton, 20 % for hay and alfafa production for cattle, and 20 % for cereals and other products. Urban and industrial needs use about 10 % of the water consumption, and are not considered to increase much with time. The remnant 2 % are used by fisheries in natural or artificial lakes but this is a renewable resource. It is well known that everywhere in the former Soviet Union a large part of the water was spoilt through evaporation and leaks due to the poor state of the canal and pipe systems, and through excess irrigation. Experts have estimated the loss to be 40 to 50 % of the total available water. Apart of spoiling water, excess irrigation water has also negative consequences, hydromorphism due to poor drainage in this flat topography and pollution of the underground aquifers as well as of the surface waters. The cost of the rehabilitation of the irrigation system will probably reach about 20 billion dollars.

The drainage water system has also been largely neglected during the soviet time resulting in salinization and pollution due for a large part to the incompletion of the system and its failures, when it existed. A part of the collected drainage water is reused for irrigation, specially for forage, but leads to a further enhancement of underground pollution. The increase of salt content in river waters is mainly due to the rejection of primary and secondary drainage water in rivers.

The present policy is to drain all waste waters to closed depressions in the deserts, such as Arnasai, Ayakagitma, Sarykamish and more recently the Unguz in Turkmenistan, where they evaporate. A better technique is to spread this water in interdunal depressions and corridors of Karakum and Kyzylkum deserts, where it is hoped that it will favor the restoration of past endemic vegetation such as saxaul, tamaris and other halophytes, for future use as domestic fuel and cattle fodder. Halophyte cultivation is also considered.

Except the northern part of the Aral lake, which can be partly restored with a new dam (money from the world bank), the remnants of the Aral lake, for which no realistic rescue program is now considered, is also used now as a sink of waste waters. The present objective to transfer about 20 km^3 per year water of the Amu Darya to some of the delta lakes such as Sudoche to be reactivated may help a little, but the Aral Sea is doomed to shrink each year a little more.

The Local Quality of Water

Central Asia always suffered from the poor quality of drinking water. An important factor of the poor health statistics is the fact that in the lower courses of the rivers, and around the cities, water is contaminated by a lot of chemicals together with pathogenic bacteria and viruses. Sewer systems and epuration stations are almost absent, even in large cities, and when they exist, only 10 % are efficient. In the villages, manure and human dejections percolate into the soil. The hygiene education is yet very defective.

To this problem of contamination is added the fact that drinking water is in many cases above all OMS norms : too much magnesium, sodium, nitrate, chloride and sulphate, heavy metals and pesticides. Here too, it is often difficult to find water, even from underground sources (boreholes), with the requested qualities.

In many cities, the municipal distribution system is obsolete and needs either rehabilitation or complete rebuilding. The lack of financial resources and an inefficient administration affect also some large cities which lack enough reserves to provide untreated or insufficiently treated river water during the summer shortage.

A number of programs of small magnitude have however been launched with international funds, the help of NGO's, and minor contributions of local and national authorities. The water system of the town of Bukhara is being rebuilt, and the Tashkent one repaired. In Samarkand, water shortages were general in summer 1998. Several regional programs have started for the region of Tashauz, Turkmenbashi, Chardzu, Khiva, the whole region of Karakalpakstan and Khorezm provinces (Urgench and Nukus), the region of Kzyl Orda and the Syr Darya cities (Kazalinsk, Aralsk), the region of Karaganda and Akmola, the new capital city of Kazakhstan.

Priority is given to the installation and the equipement for water analysis in the most important cities and the education of specialized technicians, the building or restoration of pipelines from unpolluted (or low polluted) sources, rivers or wells, the installation of local efficient tape systems, supply of bactericides (chlorine...) etc. Campaigns for the building or restoration of sewer systems and waste treatment stations have also begun. Priority is distribution and sanitation of water for schools, maternity and ordinary hospitals. Teaching hygiene principles, water economy and savings are introduced in schools. But all these operations will ask for many years.

An important effort is necessary to teach the layman how to save water, as well for the domestic as for the agricultural uses. As water is free almost everywhere, the question arose to pay for it, as well for home or for irrigation, specially because expenditures for a modern system will grow. Some experts state that this is a great problem for the poorest citizens, specially rural population, for whom a water fee should represent a significant part (10 %) of their income.

Conclusions

A recent UNESCO paper (2) has given an interesting perspective of the way things should be transformed in 2025. It stresses the need for deep transformations beyond the water problems, of the present status of agriculture :

a. shift the social status of farmers and herders through privatization, low-cost bank loans, private management products;
b. education relative to modern agriculture practices and technology, and also of management;
c. development of local industries for materials, equipment of all kinds of irrigation, drainage, chemical aids and products stockage;
d. favor the return to some sort of sensible nomadism in the less productive areas; and
e. simplify the administrative systems.

We think that the three first proposals should be discussed, on the contrary the proposals 4 and 5 should be among the first priorities. We think that the nomadism should be studied and developed with minor improvements.

On the whole, all aspects of the management of water in Central Asia involve immense difficulties.

Some of the countries of the former Soviet Union are attempting food self sufficiency (Turkmenistan, Uzbekistan), but the population is constantly growing, and even if a part of the agricultural land returns from industrial agriculture to food production (which constitutes a good part of the nations GNP - 40 % for Turkmenistan), it is insufficient. On the other hand, hundreds of acres will have to be abandoned because of salinization, if impossible to cure, but may be used for grazing, with a low output of forage.

Although more than 100 km^3 per year water are available for a population which will pass 40 million in a few years, the necessity to save water increases constantly. Therefore it will be necessary to turn towards more value-added productions, such as vegetables, fruits, and other less using water plants, such as sorghum and millet and also try to increase rain-fed agriculture, although their yield is rather unpredictable. It is necessary also, as stressed above, to look forwards beyond the present situation.

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3

Central Asian Studies in our Research Perspective – A Personal View

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Introduction

Central Asia is one of the most challenging areas for Arid Land Studies. From Tsarist Russian explorers, such as Nicolai M. Przhevalski to the present-day scientists and decision makers in and around Central Asia, have made various efforts to develop the area under political and economic interests. We owe very much to their writings and study of natural history, geography and socio-cultural life of the peoples. During my university studies which was in the unfortunate period of Sino-Japanese and the then the Pacific war between 1941 and 1946, I had the opportunity to discover Central Asia through reading excellent scientific works by eminent scholars such as Ferdinand von Richthofen, Sven Hedin, Aurel Stein, Paul Pelliot and Owen Lattimore. Chinese and Japanese historical books concerning Central Asia gave me much interests and knowledge about Central Asia or Inner Frontier of Asia. The independence of Central Asian countries after the collapse of the Soviet Union has led to many difficulties including implementation of sustainable development in the newly independent states. These difficulties are faced even with the presence of assistance from international organizations and the world community.

Some Key Issues

One of the most difficult issues pertaining to the Central Asian region relates to environmental problems, especially the water resources problems are acute and need to be urgently overcome. This is true for not only the Aral Sea basin but also in urban areas, rural settlements, grasslands and mountains. Water management including irrigation, industrial use, potable water, wastewater and pollution problems have to be viewed in relation with the sanitary conditions and transboundary river disputes.

I had the chance to participate in an international Conference on the Aral Sea (1995 - Nukus, Uzbekistan) and a workshop on the scientific program about the Aral Basin (2000 - Alamty, Kazakhstan). At the first meeting, I was much impressed by the presentation of medical doctor from Karakalpakstan who appealed for an international support to put an end to the very high infants mortality because of polluted potable water and dust. At the southern coast of the Aral sea, where it already dried up, we found an isolated fishery village called Muynak, medical doctors of the local hospital handed me a letter asking international help to supply medicine to the patients, fisher boats on the dried up former sea shore were monuments to show the dramatic sinking of the sea level. At Alamty, very hot discussions were raised from local NGO groups who condemned strongly the secret policy of Moscow to conceal on-going land degradation during the Soviet regime.

Japan-Based Activities in Central Asia

Japanese researchers working in agriculture, hydrology, industrial chemistry, remote sensing (GIS), archaeology and history are now continuing steady field work in collaboration with host countries and the United Nations University.

Major activities related to the Central Asian region were initiated by the following Japanese institutions:

- *The Japanese Association of Arid Land Studies* (founded in 1990), which has more than five hundred members, has organized international workshops for desert engineering. Several Central Asian scholars were invited to these meetings.
- *The Global Infrastructure Foundation Japan (GIF)* organized two symposiums at the United Nations University on the Aral Sea in collaboration with international scholars including eminent Central Asian scientists and decision-makers.
- *Kyoto University* which is one of the pioneer groups for Central Asia field research. Under the leadership of Professor Tsuneo Tsukatani and Professor Norio Ishida and in collaboration with Central Asian academic circles, they published several field reports including a database on the Aral Sea and discussion papers on issues such as Daily Water Flow Database from Aral Sea Basin, and Water Quality of Zerafshan River Basins.
- *The Silk Road Research Center*, founded after the completion of UNESCO's project on the Silk Road, was funded by Nara Prefecture in Japan which has precious treasures at the Shosoin Imperial Warehouse in Nara which

were brought through the Silk Road from China during the T'ang Dynasty when the Chinese had extended their influence to the former Sassanid Persian territory in West Asia. The center organized various symposiums on the Silk Road. Subjects for these symposia include spatial archeology, history and art. They have published a Silk Road map based on GIS and also a map on prehistoric and historic sites along the Amu Darya and Syr Darya basins.

A three-year project on network of researchers of Islamic world including Central Asian scholars is also well organized under the leadership of Professor Tsugitaka Sato of the University of Tokyo in close collaboration with academic circles worldwide. This project includes Central Asian studies on contemporary conflict issues. The Centre for East Asian Cultural Studies published "Bibliography of Central Asian Studies in Japan" (2 vols, 1989) which includes around 15,000 articles concerning Central Asia (East and West Turkistan, Mongolia). Because of the language barrier (Japanese to Russian or other languages), I regret that the excellent articles are not well-known to the outer academic world. Our knowledge on Central Asia is still limited especially on the contemporary situation.

Although, it is not an easy task for Japan to collaborate with Central Asian researchers or decision-makers, Central Asia constitutes one of the important focal points of the Japanese ODA, and the Japanese Government supports directly or indirectly interested international organizations including ICARDA. For instance, in the case of Uzbekistan, Japan has supported the reconstruction of a new airports at Samarkand, Bukhara and Urgench, and also continues specific development projects on water and public health issues.

United Nations University-Led Projects

One of the epoch-making symposia was held by the initiative of the United Nations University on Caspian, Aral and Dead Seas on the spring of 1995. The symposium resulted in a book published in 1998 and titled "Central Eurasian Water Crisis." This book was used as one of the pertinent references to the UNESCO General Assembly for the initiation of its project on Central Asia. However, as one of the editors of this book, I have found difficulties analyzing the environmental change in the Caspian Sea due to the continuous instability of the sea level which had increased in 1995 and decreased during 1998 where the causes had not been determined. Thus induces us to say that environmental change phenomena should be studied rather on a long-term basis.

Besides, the UNU had the opportunity to invite scientists from Uzbekistan and Kazakhastan to the Symposium on "Iran in a Globalizing World" held in November 1999 when geopolitical topics including natural resources and energy issues in and around Central Asia were discussed.

UNU has also started a series of workshops on desertification from 1998 till the present, i.e. "New Technologies to Combat Desertification" (Tehran, Iran - 1998); "Water Management in Arid Zones" (Médenine, Tunisia - 1999); and "Water Management in Central Asia" (Aleppo, Syria - 2000). As the name indicates, the last meeting particularly focused on the challenges faced by this region for managing their water resources.

Some Proposals

Under those circumstances, I would like to propose my personal view concerning how to combine on-going research projects in and outside Japan and Central Asia with special emphasis on UNU-ICARDA collaboration for the future. My proposals are described as the following:

To Support Field Research in Central Asia

Young scholars either non-residents or residents in Central Asia (for example graduate students in universities) should be supported for their field researches in Central Asia. Central Asian students have difficulties to get research funds, and students outside Central Asia need logistical support from available funding. If UNU could proceed this master plan in close collaboration with relevant international institutions such as ICARDA including Central Asian Academia, we may probably find some solutions on endowments. This program may include the support to Central Asian scholars to undertake studies abroad in the realm of same eco-regions, library or research laboratories in developed countries such as in Japan or the EU. To follow up, we may have small workshops on various topics to bring their findings not only to academic circles but also to the local inhabitants.

UNU has already started to send Japanese Graduate students for field research in Central Asia. The fund named "Akino Fund" was created for the memory of Professor Yutaka Akino who was killed in July 1998 while on active service as a Civil Affairs Officer of the United Nations Mission of Observers in Tajikistan (UNMOT). Topics for fellowships, which are flexible, are related to Peace and Environment in Central Asia. For the year 2000-2001, there are eight selected research fellows who cover the regions of Azerbaijan, Kazakhstan, Tajikistan, Uzbekistan and Mongolia. UNU is planning to have the first workshop on Central Asia during the second half of the year 2002 based on the Akino Fellows reports.

To Elaborate Specific Research Projects

There are many ongoing projects in Central Asia through international organizations, bilateral cooperation and NGOs. For example, UNESCO has a large Central Asian project covering cultural, educational and scientific aspects supported by most of Central Asian countries. Another project is being undertaken by the CGIAR group, moderated by the ICARDA Facilitation Unit in Tashkent and financially supported by the Asian Development Bank. Besides, the World Bank, UNEP, FAO, UNDP have formulated and implemented various projects in the region. The UNU could also elaborate innovative projects which will complement present ones undertaken by other institutions.

Conclusion

As the UNU is a relatively small organ of the UN system, it may use its neutral position to facilitate the networking of institutions and individual scholars and researchers in Central Asia and around the world on specific projects. Besides, our future research programme should be more oriented toward the benefit of the population of Central Asia in order improve the local quality of life.

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4

On-Farm Water and Drainage Management Strategy in Kazakhstan's Arys-Turkestan Area

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Overview

Arys'-Turkestan Canal (ATC) is situated in the south of Kazakhstan, which is considered to be an arid area with extreme continental climate. Therefore, irrigated farming is the main producer of agricultural crops in this area. However, low relative air humidity in summer, significant prevalence of potential evaporation over amount of rainfall (1:7) result in secondary salinization of irrigated lands, which account for about 70,000 hectares in the ATC zone. During the time of Soviet Union, 490 vertical wells have been installed for dual purpose of covering water deficit during the vegetation period and serving as vertical drainage wells to relieve root zone from salinity buildup and to prevent rising water table. This system annually provided 120 –150 million m^3 of groundwater that was used for irrigation.

At present, this system is not functioning and the main source of irrigation water in the ATC zone during the vegetation period is a reservoir called Bougoun; its storing capacity is 370 million m^3 of water. This volume of water in Bougoun' Reservoir is not sufficient enough to irrigate the potentially available 70,000 hectares.

Research activities on development of soil, water and crop management technology in drainage-impacted areas in ATC have been initiated. The main objectives of this research are to improve and sustain soil and water production potential and economic agricultural output in the zone of ATC and elsewhere with similar hydrosalinity conditions. To achieve these objectives, advanced irrigation technologies such as alternate furrow irrigation have been introduced and tested at the experimental plot of 50 ha area planted by cotton in comparison to traditional furrow irrigation system that is widely spread in the region. Shallow groundwater at a later stage of cotton growing is controlled to increase its contribution to cotton water demand. Results of the first two years (1999 and 2000) activities have shown that this irrigation technology is much more effective than the traditional surface furrow irrigation. Proper deployment to this strategy may not only bring sustainable economic production to farmers, but also make fresh water available for beneficial use.

Introduction

Irrigated area in the zone of Arys'-Turkestan Canal makes 70,000 ha, of which 58,000 ha are under full irrigation and 12 thousand ha are under supplemental irrigation. Runoff of the main rivers such as Arys', Bougoun', Karachik, and Ikan-Sou is the major source of irrigation water. Water resources of these rivers are being used as follows. During the springtime, floodwater is used for water supply irrigation and for irrigation of grains and perennial grasses. In the summer, when they stop water delivery from Arys River and the runoff of other rivers does not exceed 3 m^3/s, water withdrawal for irrigation is being performed from the Bougoun' Reservoir.

The experience gained by specialists during operation of Arys' Turkestan irrigation system for more than three decades justified that water-intake from Bougoun' reservoir was fluctuating from 400 to 780 million m^3, and water supply of irrigated areas varied from 60 to 100%. To cover the water deficit and to create a cone of depression pulling the salt to deeper soil stratum 490 dual-purpose drain wells for vertical drainage have been constructed.

The great misbalance in pricing has occurred during transition towards market economy: prices on maintenance and energy resources, required for functioning of irrigation system, exceeded market prices of agricultural products. Lack of sufficient governmental financial support made farmers to be unable operating the drain wells. In conditions of harsh financial limitations, only improved irrigation technology and increased use of groundwater including subirrigation are able to provide increasing of water supply and yield productivity of cultivated lands.

The existing system provided 120-150 million m^3 of annual groundwater withdrawal for irrigation. Water withdrawal from the Bougoun' Reservoir was coordinated with volume of groundwater withdrawal for irrigation. At present, the system of vertical drainage is not functioning; therefore, irrigation water demand is being covered by water withdrawal from the Bougoun' Reservoir of which the capacity is 370 million m^3. This water quantity is not sufficient enough for irrigation of the whole available arable land. Thus, the irrigation water deficit may be covered through reduction of water losses for infiltration and physical evaporation and through increase of groundwater contribution for subirrigation.

Research Site Location And Experimental Layout

Irrigation technology in one furrow interval decreases irrigation rate by 20 –25%, and use of regulating sluices by 15 to 20%. Research of salt balance during vegetation period (salt accumulating) and non-vegetation period (salt removing) has proved that salt removing prevails over salt accumulating.

The issue of water conservation is being explored at the pilot site located 3 km far from the Ikan settlement south of Kazakhstan. Figure 2 shows experimental field layout at the rectangular-shaped pilot plot of 50 ha area planted with cotton as well as locations of the irrigation water, sluice gate, drainage collectors, observation wells, and drainage layout. Collector B-1 crosses the site from the East to the West and water from the D-3 and D-4 drains is flowing into it. Depth of drains and collector is 2.5 –2.8 m. Soil surface is represented by heavy loam. At 0.6 –1.0 m depth, medium and light loamy soils are occurred. At the 2 m below the soil surface, there is a layer of compacted loams and clays. Gravel-shingle bed deposits of 11 –15 m thickness with sandy interbedding are occurred at 9 – 10 m depth below the soil surface at the first regional impermeable layer. Irrigation land-use efficiency is 0.8.

Infiltration rate of loamy deposits varies from 0.4 to 3.3 cm/hours while that of gravel-shingle beds with sandy interbeddings grows up to 150 m. Loam's yield of water is 0.11 –0.13, that of loamy sand is 0.12 –0.15, and that of gravel-shingle bed deposits 0.13 –0.18. Salt concentration of the loamy deposit's groundwater is 900 –2,500 mg/l and that of gravel-shingle bed deposits is less than 1,000 mg/l. Soil is gray-meadow. Salinity type is Chloride-Sulfate. Organic matter content is less then 1%. Field water capacity makes 21.5 – 23.3%. Bulk density is 1.44 –1.56 g/cm3. In fall, groundwater table level decreases from 1 to 3m below the soil surface.

Experimental Treatments And Description

To develop water-saving irrigation technology, the following irrigation options have been applied:

- Traditional furrow irrigation

- Alternate furrow- irrigation with constant discharge (control)
- Alternate furrow-Cutback furrow irrigation
- Alternate furrow-Discrete furrow irrigation

Research work was conducted during the dry years. Precipitation rate over the vegetation period was 7.1 –29 mm; that was 38 –59.9 mm less then the average historical rate. In April-June, the relative air humidity was 1.4 –8.1% less then the average historical data. During the other months, variations of average statistical data did not exceed 4%. Air temperature increase by 0.9-4.7°C in relation to average historical data was observed in April, by 0.8-1.7°C in May, and 1.9-2.6°C in August. These factors have sped up the cotton growth. The maximal raises of air temperature have been observed during the year 2000.

Irrigation was carried out to the furrows of 11-13 cm depth, 30-32 cm top width, and 430-450 m length. Inter-row distance was 90 cm. Double replication was used to conduct the experiment. The area of one irrigated plot made 1-1.2 ha. Observations of groundwater table level have been carried out every 2-5 days. Water reserves in the soil were evaluated by means of thermostatic-weight method down to the groundwater table level through soil sampling in the following horizons: 0-20, 20-40, 40-60, 60-80, 80-100, 100-120, 120-150, 150-200, 200-250, and 250-300 cm. Soil moisture dynamic under alternate furrow irrigation was assessed through soil sampling before and after irrigation from the irrigated and non-irrigated furrows as well as from the furrow slices. Records of water supply and drainage were performed by means of Thompson's and Ivanov's weirs for each of the options. Dynamics of cotton growth and development was recorded at the meter plots. Effect of sluice-regulator operation and irrigation technology on groundwater regime was evaluated through observations of regime drains.

Cotton-growing agricultural techniques were used according to farming systems appropriate to the given region. Mineral fertilizers (ammonium nitrate) were applied before the first and second irrigation with application rate of 35 kg/ha. Weed control practices were performed by means of weeding by hand after inter-row treatment.

Irrigation Scheme, Results And Discussion

In the Arys'-Turkestan Canal Zone, surface furrow irrigation is the most widely spread irrigation method. Water distribution to the irrigated plots is conducted from temporary irrigation canals. Water supply to the furrows is carried out directly from the temporary irrigation network. Specific extent of this network is 40 – 60 linear m/ha and its efficiency is 0.95. Some 30 –40% of water losses is used for moistening the soil of the lands adjacent to the temporary irrigation canals. Reinforcement of the furrow's headstall has been conducted by means of plastic film (polyethylene sheets) and distribution boards (Photos 1 and 2).

Efficiency of furrow and alternate furrow irrigation technologies were evaluated through soil moisture content and irrigation water losses by infiltration, evaporation, and surface runoff. Under on-farm options (furrow and alternate furrow irrigation), within the first 10-12 hours water discharge to the furrows varied from 0.7 to 0.9 liter per second (l/s), and then it was reduced to 0.3-0.5 l/s. First adjustment of water discharge in some furrows has been conducted 7-8 hours after the beginning of irrigation, and the second adjustment 2-3 hours after reduction of water discharge to the furrows. General regulation of water discharge to the furrows has been performed through changing water horizon in the temporary irrigation canals (by means of reaches). Water discharge regulation between the reaches was carried out through polyethylene reinforcement of cofferdams.

Under furrow irrigation option, irrigation water has been used as following: 51-54% of the total water supply was used for soil moistening (saturation), 20-25% for infiltration within the temporary irrigation network and in the fields, 5-6% for the evaporation from water surface, and 18-21% for surface runoff. Significant quantities of irrigation water losses by infiltration and surface runoff (about 40% of total water supply) reduced water supply to the irrigated lands and decreased the efficiency of agricultural production as well as the reliability of drainage systems. This irrigation technology has sped up the processes of decomposition and removal of organic elements and mobile forms of nutrients in the root zone that eventually, brought to soil fertility losses. Therefore, it was feasible to introduce alternate furrow irrigation schemes.

Application of alternate furrow irrigation (water management practices in the temporary irrigation canals and furrows remained the same) has improved irrigation water use. Under this furrow irrigation system, 56.7-72% of the water supply has been used to replenish soil moisture, 12-21.1% for infiltration within the temporary irrigation network and in the fields, 4.4-4.7% for evaporation from the water surface, and 11.3-17.8% for surface runoff. Reduction of flooded area and maintenance of aerated soil layer on the largest part of irrigated lands have slow down the process of organic element denitrification and removal by infiltration water. Agricultural crop productivity has been increased even after reduction of application rates of mineral and organic fertilizers. Working conditions of labors carrying out irrigation process were improved as this technology allowed them moving on the dry furrows.

The water application rate under traditional furrow irrigation was 4,600 m^3/ha per year and that under alternate furrow irrigation with constant discharge rate (control treatment) was 3,200 m^3/ha in 1999 and 1,320 m^3/ha in 2000. Under cutback irrigation, regulation of water discharge to the furrows has been conducted for the purpose of providing minimal surface runoff. During the first 8-10 hours, water discharge to the furrows has varied from 0.7 to 0.9 l/s with further reduction to 0.5-0.7 L/s. After 15-17 hours, water discharge has been decreased to 0.3-0.5 l/s. The irrigation time was 24-28 hours. Uniformity of water distribution within the irrigated field was provided by regulation of water discharge to the furrows after 5-7 hours of irrigation. Water discharge to the furrow has increased in case the water did not run to the edge of the field; in the furrow of surface runoff forming water discharge has reduced. This method has been used to estimate water discharge to the furrows and it was according to the soil absorption capacity. Efficiency of irrigation water use under application of this technology can be evaluated through water losses. For soil moistening 61.7-81.1% of water supply was used, 10.3-21% was lost by infiltration, 4.9-5.0% by evaporation from the water surface, and surface runoff made 3.6-12.4% of the water supply.

Discrete irrigation, water supply to the furrows has been conducted through periodic water intake from the irrigation canal. During the first 9-10 hours, water discharge to the furrows has varied from 0.9 to 1.1 l/s. After the first three irrigation periods, water discharge to the furrows has been reduced to 0.6-0.8 l/s and after the second three periods to 0.4-0.6 l/s. Time of each period was estimated according to the time needed to the water to cover 80% of the length of run. In the first irrigation period, water flow covered this distance in 3.5-4 hours, under the second period in 2-2.5 hours, and in the third one in 1-1.5 hours. Intervals between irrigation periods lasted for 1 hour. After each reduction of water discharge to the furrows, the time of irrigation period did not vary. Uniformity of water distribution was provided by regulation of water discharge to the furrows during the 1st, 4th, and 7th irrigation periods. Irrigation time was 26-32 hours. High efficiency of irrigation water use can be proved by water loss records: for soil moistening 64.2–74.5% was used, water losses by infiltration were 12.0–19.9%, by evaporation from the water surface 5.4–5.5%, and water losses by surface runoff made 7.7–10.4% of the total water supply.

Regime of water supply to the furrows has not significantly affected the processes of moisture accumulation in the soils. These processes depended on the time, during which water has stayed in the furrows, on the threshold of pre-irrigation moisture content, plowing and loosening depth in the inter-row spaces. In 2000, the threshold of pre-irrigation moisture content decreased to 5%, plowing and loosening depth in the inter-row spaces increased by 3–5cm in comparison to the previous year (plowing to 28–30 cm depth, loosening to 10–12 cm depth). These factors facilitated growing of the absorption rate and contributed to the increase of soil moisture content. Maximal rates on moisture accumulation and minimal ones on water losses (infiltration, evaporation, and surface runoff) were observed in 2000. Low rainfall and dry year have changed the psychology of the people. Thus, the grower started to use practices that save water. It can be proved by water-balance observations (Table 1).

Improvement of irrigation technology has changed the characteristics of water discharge within the water balance system. Under cutback irrigation (water discharge to the furrows was according to the soil absorption capacity), operation water losses were reduced to the minimum and accounted to 21.5% of water supply. Under discrete irrigation, water losses have increased to 24.8% and under control option, up to 26.8% of water supply. High efficiency of irrigation water use is proved by water consumption per unit of crop. Under control option, water consumption was reduced from 1,430 to 720 m^3, under discrete irrigation from 1205 to 630 m3, and under cutback irrigation, from 1250 to 600 m^3 per ton of cotton yield.

Significant reduction of water supply and irrigation water losses by infiltration (in the irrigated fields) resulted in slowing down the process of salt removal from soil and facilitated seasonal salinity buildup. Positive salt balance has increased and made 1.5 t/ha. Comparison of soil salinization in fall and spring (October-May) has shown that during the non-vegetation period, rainfall and moisture supply irrigation contribute to removal of 0.8–1.0 tons of salt per ha. Little time differences of salinization and desalinization processes are caused by low level of salt content in the soil and groundwater, good quality of irrigation water (mineralization less than 500mg/l), and water and salt transport between the aquifers. Under irrigation, infiltration flows have intruded into groundwater flow of gravel-shingle bed deposits thus, facilitating the salt removal. During the irrigation intervals, a vice versa process has been formed: fresh groundwater of gravel-shingle bed deposits intruded into the aquifers of cover deposits causing their desalinization.

Data on salinity buildup and salt removal show that utilization of sluice-regulator has not led to degradation of soil reclamation status on the irrigated lands. During the main period of water year starting in fall (September) until summer (June), drainage network will perform its functions by providing decrease of water level. During the second part of vegetation period (July-August), when water deficit may lead to yield reduction, it is necessary to maximally utilize groundwater for subirrigation. This could be done through blockage of drainwater flow by sluice-regulators. Accumulation of drainwater in the drainage network has changed the functions of the latter. Instead of decreasing water level, it provided replenishment of groundwater by means of inter-system redistribution of drainage runoff. It can be proved by changes of groundwater level regime (Figure 2).

Research has proved that before construction of the sluice-regulator, daily groundwater level could be decreased by 2-2.5 cm. After the sluice-regulator had been constructed and put into operation, time of groundwater depletion has decreased more than twice never exceeding 1 cm per day. It increased the groundwater contribution for subirrigation and facilitated normal cotton growth till the 20 August, when the sluice-regulator was not functioning. The daily groundwater depletion rate exceeded 2 cm that sped up the drying-out process in the soil root zone leading to early cotton pod abscission. Predicted cotton productivity has decreased from 3.6-3.7 t/ha to 2.2 –2.6 t/ha (Table 2).

By the end of June, water of Bougoun' Reservoir has been drawn-off. Cut of water supply to the Turkestan main canal has sped up the groundwater depletion to the depth of drainage network. By the 20th of August, the process of drainage runoff forming was interrupted; therefore, sluice-regulator was not able to perform its functions. Groundwater contribution for subirrigation is predetermined by volume of water supply to the irrigation system and by amplitude of groundwater table variations.

According to historical data, amplitude of groundwater table variations depended upon volume of diverted irrigation water, technical status of irrigation and drainage networks, and irrigation technology. During the spring (April), when moisture supply irrigation is being conducted while the precipitation rate is very high, the inflow of groundwater from the adjacent areas increases and groundwater level raises daily by 3–5 cm. In the beginning of May, on the larges part of irrigated area, the groundwater occurrence is observed at 1–1.5 m depth. In the second part of the month, the process of groundwater depletion starts in all places. Daily, groundwater table falls down by 1.5–2.5 cm. Under irrigation, the inverse process, rising of groundwater level, is being occurred. Variations of groundwater level are being limited by water losses for infiltration and deep percolation within all the components of irrigation system. Reduction or cut of water supply inevitably increases groundwater depletion rate. This factor indicates good hydraulic interaction between certain aquifers.

Utilization of sluice-regulators will certainly increase water supply to the irrigated lands (particularly, in poor water years) through rising of groundwater contribution for subirrigation. Feasibility of sluice-regulator utilization is economically justified. Capital cost does not exceed 50 US$ per 1 ha, while operation cost is not higher than 8 US$ per 1 ha. Drainage management does not interrupt the sequence of implementing technological operations related to agricultural crop growing and reduces the number of irrigation events and water losses by physical evaporation.

Summary

Different alternate furrow irrigation schemes were tested in Arys'-Turkestan region of Kazakhstan, where the irrigated land is being hampered by drainage problem and irrigation water shortages. Cotton-based crop rotation is the main crop production system in the area. Introduction of the different irrigation schemes compared to the traditional furrow irrigation was combined with the study to enhance shallow groundwater contribution to crop water use by installing and putting into operation a regulated sluice gate. High efficiency of irrigation water use is proved by water consumption per unit of crop. Under control option, water consumption was reduced from 1,430 to 720 m3, under discrete irrigation from 1,205 to 630 m3, and under cutback irrigation, from 1,250 to 600 m3 per ton of cotton yield. Utilization of sluice-regulators will certainly make a significant contribution to meet the crop water requirements and, in turn, save considerable amount of irrigation water for other beneficial uses. Feasibility of sluice-regulator utilization in this experiment was economically justified. Capital cost did not exceed US$ 50/ ha, while operation cost was not higher than 8 US$ 50/ ha. Proper deployment to these alternate furrow schemes combined with control over shallow groundwater at certain time of the cotton growth may not only bring economic benefits to farmers, but also to the environment.

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Table 1. Different Irrigation schemes and water balance of the research site, m^3/ha

Irrigation Options	Soil layer, cm	Water supply (Gross irrigation rate)	*Precip.*	Water losses		Moisture content		Evaporation and Trans-piration	Subirrigati on/ ground-water contri-bution	Cotton yield
				Evaporati *on and* surface runoff	Infiltratio n	Initial	Final			
Traditional furrow irrigation	0-100	4,600	350	1,100	800	2,560	1,850	6,650	2,800	2.35
	0-200	-"-	-"-	-"-	-"-	4,400	4,400	-"-	1,350	
Alternate furrow irrigation-constant furrow flow (Control)	0-100	3,200 1,435	225 71	630 215	500 170	2,700 2,750	1,900 1,250	6,050 5,700	2,955 3,079	2.24 1.95
	0-200	-"-	-"-	-"-	-"-	6700 6750	4500 3880	-"-	1,555 1,709	
Alternate *furrow* irrigation-Cutback irrigation	0-100	3,000 1,320	225 71	450 125	460 155	2,700 2,750	1,850 1,300	6,100 5,750	2,935 3,189	2.40 2.20
	0-200	-"-	-"-	-"-	-"-	6,700 6,750	4,450 4,000	-"-	1,535 1,889	
Alternate *furrow irrigation* -Discrete irrigation	0-100	2,650 1,350	225 71	360 180	400 160	2,700 2,750	1,800 1,300	6,000 5,700	2,985 3,169	2.20 2.10
	0-200	-"-	-"-	-"-	-"-	6,700 6,750	4,400 3,980	-"-	1,585 1,849	

Note: numerator is 1999 data; denominator is 2000 *data.*

Table 2. Effect of irrigation technology on cotton growth under alternate furrow irrigation

Options	Irrigation rate, m^3/ha	Sowing date	Germination date	Date of observations					
				2 July		14 August		18 September	
				Plant's height	Number of pods	Plant's height	Number of pods	Plant's height	Number of pods
Control	3,200 1,435	3 May 23 May	10 May 29 May	21 21	20 -	68 60	75 90	76 60	55 56
Cutback irrigation	3,000 1,320	-"-	-"-	19 22	18 -	65 61	76 92	76 61	60 65
Discrete irrigation	2,600 1,350	-"-	-"-	20 20	20 -	63 55	73 96	73 55	56 62

Note: numerator is 1999 data; denominator is 2000 data

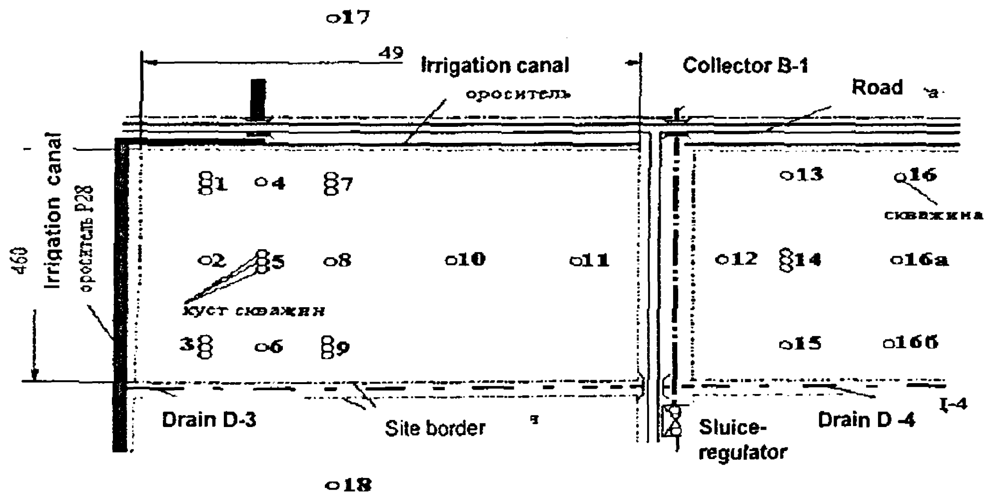


Figure 1. Scheme of the experiment set up at the research site

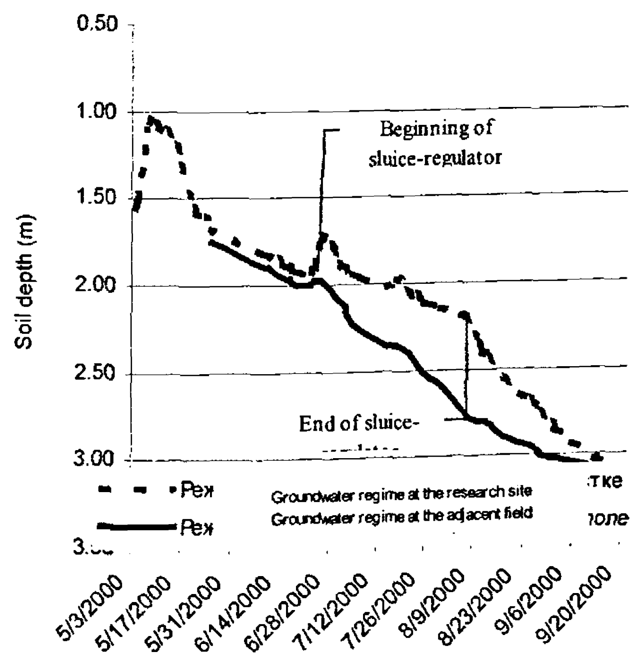
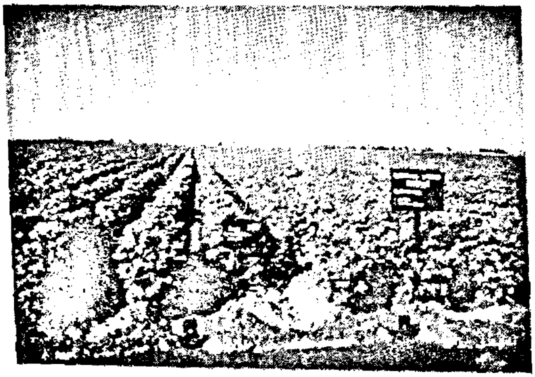


Figure 2. Effect of sluice-regulator operation on groundwater regime

Photo 1. Furrow reinforcement utilizing polyethylene film.

Photo 2. Furrow reinforcement utilizing distribution boards.



5

Soil and Water Resources in the Agricultural Sector of Tajikistan

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Introduction

Tajikistan has a shortage of arable land as its area contains only 18 % of the agricultural lands (on an average 0. 11 ha per capita).. Tajikistan is currently in a stage of transition to market economy. This transition is being accompanied by a number of negative processes such as deterioration of physical and organizational infrastruture, decline of GDP and the living standard of people. The economic situation was also affected by the chaos created by civil war and its related consequences. Negative economic processes of transition period were apparent also in irrigated farming, which involves 70% of the country's population. The serious problems related to the economic situation have resulted in the fall of soil fertility and exposed to to many ecological problems.

Government Reforms in Tajikistan

The Land Reform actions have been undertaken by the Government of Tajikistan in order to improve the productivity of land use in the republic. Since 1991, the Supreme Council has approved the Law on Dekhkans and Dekhkans Collective Farms as well as the new Land Code. The forming of legislative base for agricultural land use and government control regulation, have been started according to the worldwide standards. In the sphere of land ownership, the private property comprises a significant share. By the end of 1998, 10207 dekhkans (farms) had been established. Presently, the land management system is in a transitional stage and has a contradictory characteristics. The Government of Tajikistan is implementing the necessary actions for regulating the process of soil records and establishing the land market. The status of the land use in Tajikistan demands developing and introducing new soil conservation technology.

Irrigation Management in the Agricultural Sector of Tajikistan

The natural environmental conditions of Tajikistan are similar to the arid belt. Out of a total of 4 million ha of agricultural land, 27% are arid and 32% semi-arid. In these areas, the ratio of evaporation to precipitation varies between 8 to 24. For this reason, irrigation of agricultural lands is very essential for economical crop yield .

Low efficiency of water consumption in agriculture is one of the big problems. Lack of material and technical resources, destruction of their distribution systems and destruction of the irrigation system infrastructure have resulted in soil degradation by salinization and water-logging. Anther result of this is a decreased productivity of crop production, that reaches to 50- 60%, poor crop quality. Also, higher energy for pumping is required. This situation demands a serious attention, because it defines the ecological condition of irrigated lands in the future. Therefore, nowadays Tajikistan has more than 116,000 ha of saline and above 30,000 ha of waterlogged land. The irrigation and drainage waters in higher evaluation zones of valleys raised the groundwater level in the lower lying lands and territories, so that it becomes to close (1-2 m) to soil surface.

Table 1. Saline soils in Tajikistan in last 20 years, thousand ha

Year	Total irrigated area	Light saline	Medium saline	Heavy saline	Total salinized area
1980	633.8	78.3	20.4	12.1	110.8
1990	689.7	69.1	23.7	8.6	101.4
1996	720.0	75.6	26.3	7.6	109.5
1998	703.0	80.0	28.0	8.2	116.2

Development of irrigation in the republic had been accompanied by increase of water usage. In 80- years it was 5.5 km^3/year; now it is about 11.2 km^3/year with water consumption above 20,000 m^3/ha/year. Such negative consequences exist due to ineffective use of irrigational water and great losses of fresh water. As a result, 30,000 ha irrigated lands is exposed to secondary salinization and waterlogging. In this connection, salinization and waterlogging are the main problem in the terms of the developing sustainable agriculture.

Degradation processes and their various combinations cause different damage to the whole territory of the Tajikistan. Only a few attempts are known to evaluate influence of soil salinization on the total cotton production. According to this calculation, the country annually loose 70-100 thousand tons of cotton, 100-150 thousand tons of grain, 400 million m^3 of irrigation water and 2.5

thousand tons of nitrogen-potassium fertilizers in drain water. Irrigating of 100-110 thousand hectares of upper land resulted to increase ground water level and salinization of soil on the lower located territories, for example Hojamaston, Nau-Proletarian and others.

And some more words about the irrigation management during the 1970-80's. Salt balances of many irrigating massive had neutral or negative effect. Especially as it relates to Vakhsh valley, which was the typical example of desalinization and was publicized in the world's literature (Kovda, 69). However in next few decades, as a result of old as well as of new negative factors of agriculture, signs of secondary soil salinization appeared.

Soils of serozem-desert belts are influenced by water erosion as well as by water-wind one. Certain law of expressing are observed that in process of absolute height increase water erosion grows too. Scale of water erosion increases from sub-belt of light serozem to serozem from 22.5 up to 55.5%. In the soil-climatic belts of middle mountain (mountain brown soils) it increases to more (77.7%). Relief effects on the increase of soil areas of steep lands on mountains slopes.

Table 2. Eroded soils in Tajikistan

	No erosion	Extent of erosion			Water erosion	Wind erosion	Total eroded soil
		Poor	Med.	High			
Arable land	41,2	19,6	18,6	12,8	51,0	7,8	58,8
Pasture	11,1	17,7	23,1	20,2	61,0	27,9	88,9
Badland	6,0	6,0	15,4	39,0	60,4	33,6	94,0
Total	17,7	14,8	30,1	23,9	58,8	23,5	82,3

Management Challenges

Topography of the lands and the territory of Tajikistan, high slopes, sandy soils, saline soils, and low fertility of virgin soils are the main natural factors which rise the problem of irrigation

The country is now increasing the area for wheat cultivation, but most of its water distribution system was designed for cotton. Additionally, the following problems are present:

- Poor maintenance of canals, pumping stations and drainage systems;
- Lack of water controlling instruments for flow rate;
- Small plots of land of our farmers;
- Accumulation of erosion sediments in the drainage systems;
- Inadequate water consumption according to the yield of crops; and
- Loss of surface water.

Improving water management for sustainable development in Tajikistan may involve the following measures:

- Utilization of limited rainfall by using water harvesting technology;
- Use the technology of crop production for controlling soil erosion;
- Use of sewage water, drainage water for irrigation;
- To improve irrigation technique and increase efficiency use of water;
- Development of research plans for reclamation of saline, sandy, waterlogged and compacted soils; and
- Development of landscape agriculture which include adaptation of crop rotation, crop placing, tillage system, fertilization system and irrigation system to the landscape.

6

Community Participation and Water Management in Balochistan, Pakistan

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Introduction

The issue of increasing water scarcity and mismanagement has been of great concern to governments, private organization, non-government organizations, and people themselves in all countries. The intensity of problem is becoming severe as the population is increasing, resources are shrinking or mismanaged, especially in the arid regions of the world. Usually in arid regions, the human settlement pattern also makes it difficult for governments to provide water to each and every body especially for human consumption purpose. Limited water resources availability, inappropriate actions of remedies including high cost to develop new resources makes the situation difficult in the arid regions especially when tackled by the government. The competition among different uses is also increasing in these regions. The problem is further aggravated by poor implementation and maintenance of this precious resource especially when addressed by public sector alone under the conventional approaches on purely technical basis. The inappropriate pricing policies and negligence of community participation has increased the problem intensity also. However, on the other hand under similar situation people have been managing these meager resources effectively through their own human and material resources, institutions and skills.

Since the emergence of modern states the service delivery system has been considered the responsibility of government alone and is true in case of water sector too. In the early periods, governments have been meeting people's requirements effectively with modern technology and specialized manpower, though on a lesser scale. Different problems have been faced in meeting the needs due to increase of coverage to a wider population, older installations/schemes and decline in governance. Governments mostly with donors' investment tried to solve the problems but usually the objectives of these initiatives have not been fully achieved. The solutions of water sector from government side have been on a sectoral approach basis. As a result several problems started arising specially after the completion of these projects. On the other hand people run/operated water projects have been fully functional in most of the cases in a similar situation. There is sufficient evidence where people's experiences have been proved successful.

There are learning opportunities available for government line departments in order to address the issue of water crisis accordingly. Luckily Balochistan province is rich in people managed water resources experience in Pakistan. There is enough evidence where government, donors, sectoral experts and private organizations can benefit from them. Karez water and flood-water management system in Highlands and Kachhi plains respectively are the best examples of community water managed systems. There are also new and useful experiences within the donor funded and government executed sectors in the province.

Pakistan' population is 135.28 million according to 1998 census and its total area is 796,095 square kilometers. Its 67 % population lives in rural areas. It is the seventh biggest country by population in the world but its area is 0.67% of the world's land. Its total cropped area is 22.14 million hectares. The Indus basin irrigation is of prime importance to the economy of country. It is the largest contiguous irrigation networks in the world (IMMI, 1999). The current user fees are can not meet the operation and maintenance cost of the system and thus irrigation services are declined in the country.

Balochistan is the biggest province of Pakistan by area; 347,000 square kilometers. This comes to 44% of total landmass but its population of 6.6 million is only 5 % of country's total population. The area is characterized by arid climate predominantly. Most of the areas receive only 150 mm rainfall annually, mostly in winter season when it is not much needed because plants are in dormant condition.

Its 85 % population of total 6.6 million lives in rural areas in small settlements. Agriculture and livestock are the main economic activities in the rural areas. Due to traditional and historical practices in the arid climate of Balochistan the rearing of small ruminants is dominant in the farming system of province. Balochistan contributes 46% sheep, 23% goats and 41% of camel to a total population in Pakistan. According to 1994-95 figures its cultivated area is 1.69 m hectares, irrigated areas by all means counted for 0.85 million hectares, non irrigated is also 0.85 million hectares. Whereas, culturable waste is 4.373 million hectares and rangelands cover 21 million hectares. Area under forest was 1.09 million hectares in the province during 1994-95.

In Balochistan irrigation in three out of 26 districts is done through canal system. In two districts (Naseerabad and Jaffarabad) the canal irrigation system is a part of Indus water basin. Its total cultivated area in 1996-97 was reported as 1.68 million hectares.

The agriculture, in 23 districts of total 26, is done through control of flood-water, rain, Karezes, springs and tube wells. Presently there are 800 Karezes and more than 21000 tube-wells in the province. Area above 1000 meters altitude has been classifies as highland in the province. The valleys between mountains have been grouped according to their hydrological settings into three main units. These are the major physiographic areas in the province; Indus basin tributaries drainage connected to Indus river, coastal basin where streams drain into Arabian sea and the inland closed drainage basin (CAR-UNDP, Balochistan, 1998).

The Problem

Balochistan features a typical arid and semi-arid climate with low and erratic rainfalls. There are not many water bodies in the province. In highland Balochistan high value crops such as apple, apricots, grapes, melons, almond, cherry, onion, potatoes are grown through tube-well irrigation. There are more than 20,000 tube-wells throughout the province. The increase in tube-wells started from 1970s with the subsidy programme from government, introduction of modern technology and a part of greening the province. The increase in tube-wells number has been recorded from 1904 in 1970 to 21059 in 1996-97. Over the past 20 to 30 years water table in many areas of highland Balochistan is dropping at the rate of 8 to 10 feet a year. This decline of water table is due to indiscriminate installation of tubewells by private individuals. Karezes, springs and other natural flows in seasonal streams are also drying up due to installation of wells, low rains and irrational use of water at field level. The desertification process has started in these areas due to decline of water table. The over use of ground water may result into a poor quality. The problem of decline of water table is serious in the highlands of Balochistan which comprises approximately 53% of the province. The high value orchards mainly apple of exotic varieties consume several times more water than the traditional crops. In the scenario of present Balochistan where institutional support and technology has led to situation of drought like conditions by over mining of water, the issue of water crisis has become very complex.

Balochistan has a considerable amount of flood waters, under surface water resources, and presently is not properly utilized for agriculture. There are many seasonal rivers and streams in the province and flow during the rainy season. Few decades ago the flood water used to irrigate big areas, mostly in the plains of province, under a community based water management system. Although there are enough experiences where community based flood water management system functioned for centuries and provided food and fiber demands for majority of its population in the province. This system is not only low cost but also environment friendly.

To cope with such situation in a fragile ecosystem like Balochistan, professionals and government machinery dealing with water sector are raising questions like "is the province lacking water resources or proper management or both? "

Table 1. Number of Tube-wells in Balochistan

Years	Electric	Diesel	Total
1970-71	918	986	1,904
1980-81	3,310	3,854	7,164
1990-91	8,146	7,002	1,5148
1994-95	8,580	8,988	1,7568
1996-97	11,579	9,480	21,059

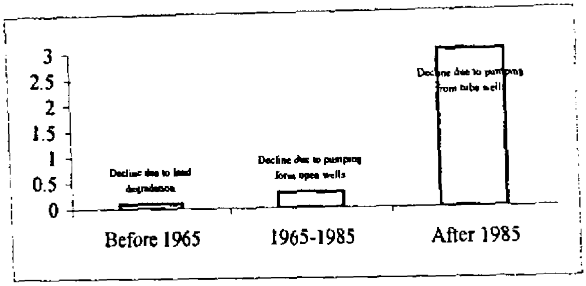
Source: Agricultural statistics of Balochistan, 1997

Table 2. Area Irrigated by Different Sources (000 Hectares)

Years	Canal	Tube-wells	Other Sources Karez, springs etc.	Total
1970-71	247.5	20.3	232.9	500.7
1980-81	383	66.2	81.7	530.9
1990-91	442.8	152.8	47.8	643.4
1994-95	493.7	229.1	94.7	817.5
1996-97	501.40	247.7	78.6	827.7

Source: Agricultural statistics of Balochistan, 1997

Table 3. Water Table Decline in Highlands Balochistan
Source: CAR - UNDP, Balochistan, 1998



Government's Approaches:

Over the years, many efforts have been applied to address various sectoral aspects of water by the governments. These improvements cover different uses of water such as drinking, sanitation, industrial, irrigation, and environment. For this purpose heavy infrastructure investments were allocated in national and provincial plans. Lack of any effective mechanism applied to coordinate the activities of different departments remained chronic. This included their budget allocations, projects, regional and area coverage, needs and priorities in different locations, effective mechanism in the design process. As far as implementation is concerned it is usually done through contractors.

Social versus Technical:

In order to reverse or at least maintain the situation many strategies have been applied and suggested. Mostly the focus has been on the supply side of the resource, i.e. number of water schemes to be increased by drilling new wells, dams, and reservoirs etc. Unfortunately the other side of problem has not been sufficiently taken into consideration as the way it should have been, i.e. how to make rational use of existing resources/supplies, its conservation, management and role of communities themselves. In some cases implementation, use and management aspects have been addressed by a single department such as management of water courses by agriculture department. In this particular case the delicate task of water management has been practiced by the purely technical staff like engineers and agriculturist who usually lack social and organizational aspects of the resource. In case of irrigation department, recently the department has been restructured as Balochistan Irrigation and Drainage Authority. It is expected that newly restructured authority will be able to address the issue in a more comprehensive way. Department/authority still lacks multi-sectoral team approach within the department.

Coordination of Different Stakeholders:

There is also a lack of coordination among different departments working on improvement of same resource. Typical examples are small scale irrigation structures construction across the perennial flows throughout the province. The schemes are assessed technically and socially as well. The structures are designed and executed by engineers of irrigation department and made by contractors. The focus is on the design and quality of civil structure, community participation and also on down stream area, i.e. command area. In this case agriculture department is also involved. But the most crucial point is about the management of upstream areas – the equally important side of the same resource base. A good work is being done on structure and command area through community participation but one of the most important aspects of up-stream area not included in the project design. The biological work in the upstream is in many cases job of forest department. This should have been done simultaneously through activities of watershed so as to reduce the erosion and increase the recharge. This would have helped to increase the life of dams and supply of water also. Enough community involvement experience has been gained but not yet institutionalized within the department such as recruitment of social scientists.

Economics and Governance:

In Balochistan flat rates of electricity do not provide any incentive to a tube-well owner to start rational use. The tube-wells are run 24 hours a day throughout the year. The decline of water table in these areas have been recorded from *8 to 10* feet per year. The rules to prohibit any further drilling of tube-wells are not implemented due to weak governance and political will.

Traditional Community Participation Approach:

In high land Balochistan integrated water resources management is not difficult or new especially in the context of local resources management approaches among indigenous communities of Balochistan. Holistic approach to water has long been practiced by these communities, i.e. Karez and water coming from hill torrents have been effectively acquired, allocated, distributed and managed by these communities without external institutional support for centuries. In fact local institution of Karez village has been the most powerful till recent past. Traditionally people have been addressing the complex issues of water through local institutions based upon the indigenous organization, rules and regulations. Karezes, the underground channels, have been constructed and managed by local population effectively since centuries. The village based organization also emerged and developed around the Karez system. Through this system water rights have been accepted, practiced and managed even in drought like conditions during particular extreme climate cycles. Under traditional Karez system, water and catchment area is considered a common property of a village, tribe/sub tribe or a group of people.

The local version of community participation includes integrated management of water by fostering information exchange and helping to match needs with available knowledge, linkages with other sectors, assistance and resources required for any sustainable project. The acquisition of site, allocation of water rights, distribution of water, and its management have been practiced through local decisions making process very well.

Box 1.

The problem of water shortage is seen by the corrupt official as an opportunity to suggest costly solutions involving donor's money, preparing high cost feasibility studies, hiding the previous reports and arguing for the new studies and new alternatives. Drinking water for Quetta town can be brought from the Sukkar barrage or Naseerabad canal some 350 to 500 kilometers away - has been suggested by some of the experts within public sector. In doing so, water needs to be pumped from 200 feet to 6000 feet above sea level and one can imagine the amount of energy needed and its cost. After all these officials have to live upon such high cost solution. This is the point where most of the experts in the government together with their allies within the political sector compromise. By suggesting so they forget or take for granted that money will be available from somewhere - probably the generous donors, interested to pour money anyway, because in any case they can take it back.

Box 2.

> As far as Pakistan is concerned, federal government has planned new water projects to be launched in near future in Sindh, Balochistan, NWFP and the Punjab. It will cost Rs 700 billion for enhancing water resources across the country on top priority besides boosting agriculture production. Further to this, an expenditure of Rs 2850 million for the studies of these projects is required. As far as rehabilitation of old mega schemes is concerned Tarbela dam alone will require at least 100,000 trucks each of 5.6 Tons capacity round the clock for 25 years to dispose off the existing delta in its reservoir.

Recommendations

Past three decades have shown some promising lessons learnt about different aspects of community involvement and its role in decision-making as under.

1. Integrated water resources management framework is an aspect that needs to be included while addressing the issue of water management, i.e. by improving cross sectoral networking, and to improve understanding with different departments related directly and indirectly with issue of water and other environmental sectors.
2. Institutional frameworks include: privatization, private sector participation, regulatory mechanism - output /mining (quantity), cropping pattern management - over supply, under supply, incentives, penalties, rules and regulations and frameworks for conflict resolution within different stakeholders.
3. Resource mobilization for sustainability includes pricing of water, subsidies, cost recovery and willingness to pay, local resource mobilization, operation and maintenance of services and micro credit.
4. National/provincial database including targets, indicators, and monitoring and evaluation methodologies.
5. Having a regional database of resources, trend in use, problems faced, strategies and lessons learnt. This can be effectively true for a region like central Asia where resource, its use, and local organizations have sufficient experience.

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7

Energy-Efficient Water Treatment Technologies

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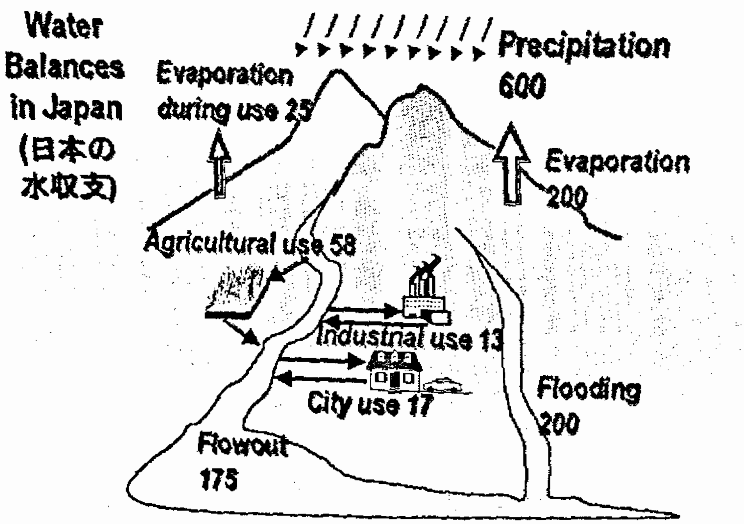
Introduction

Water scarcity is a major problem facing the world today. Considering the limited precipitation available in any given region, the key question is that how should we cope with the increase in population and per capita consumption. This problem has to be viewed in the perspective of the uneven distribution of precipitation at the global scale and the numerous transboundary management issues. Additionally, the global climate change may have unexpected impacts on the water resource distribution.

As an example, the distribution of water resources in Japan is shown in Figure 1.



Unit: 10^9 ton/year

Figure 1. Water balances in Japan

This situation can be compared to the water availability and stress in various countries; as shown in Figure 2. A number of countries in the Asian region have water use in excess of their water availability. These countries include Afghanistan, Bahrain, India, Iran, Iraq, Israel, Jordan, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, South Korea, United Arab Emirates and Yemen. In this context, treatment of wastewater and its re-use become critically important.

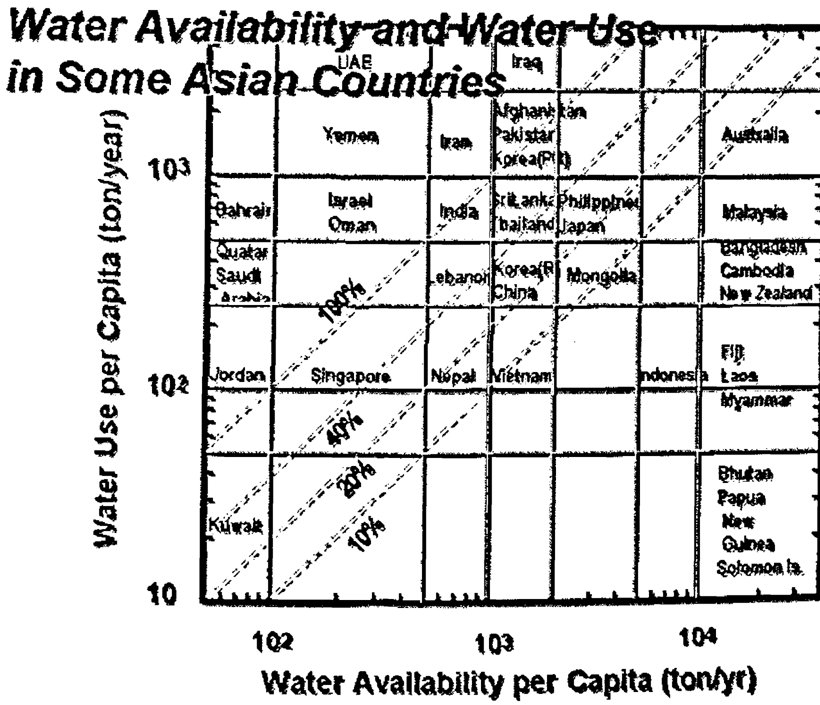


Figure 2. Water availability and water use in some Asian countries

Brief Introduction to Biological Treatment of Water in Japan

The biological oxygen demand (BOD) in the wastewater is reduced according the following reaction:

$$BOD + O_2 + \beta \text{ nutrient} + \text{biomass} \rightarrow (1\text{-}\alpha)\, CO_2 + (1+\alpha) \text{ biomass}$$

Two key issues are how to supply oxygen to the biomass and how to keep the biomass stable. The biomass can be suspended or fixed within a treatment unit. Other key issues include ways to separate water from biomass and to remove excess (grown) biomass.

A number of biological treatment options – aerobic in nature – are discussed in this paper. Some technologies, like activated sludge process and fixed film bioreactor are "industrialized" systems that operate on electric power. Other systems, like soil infiltration, oxidation ponds and zero emission systems rely on natural energy on the small scale.

A. Activated Sludge

There are four types of activated sludge systems used:

- Conventional process; high-rate with biosorption
- Sequential batch operation
- Oxidation ditch
- Membrane separation (shown in Figure 3)

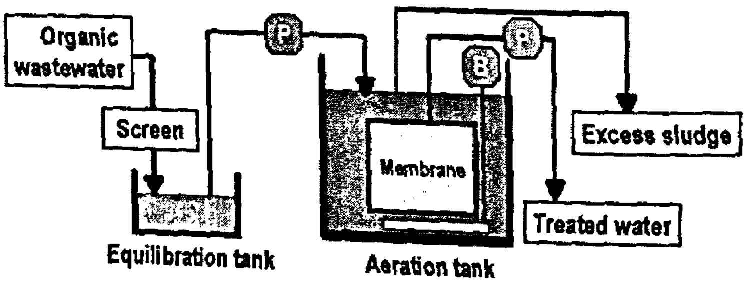


Figure 3. Activated sludge tank with membrane separation of treated water (Membrane bio-reactor)

B. Fixed Biofilm Reactor

Three common types of biofilm reactors are:

- Trickling filter
- Rotating disc contactor
- Small scale systems based on natural energy

C. Soil infiltration

This an aerobic biological treatment, the process is schematically shown in Figure 4. A typical design of a soil infiltration system is shown in Figure 5.

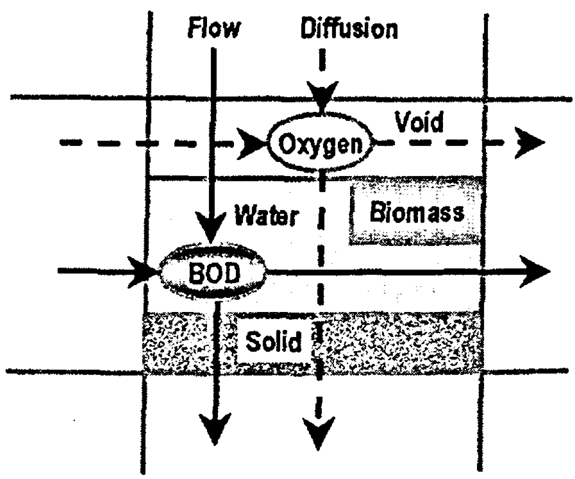


Figure 4. Unit model cell of soil infiltration system

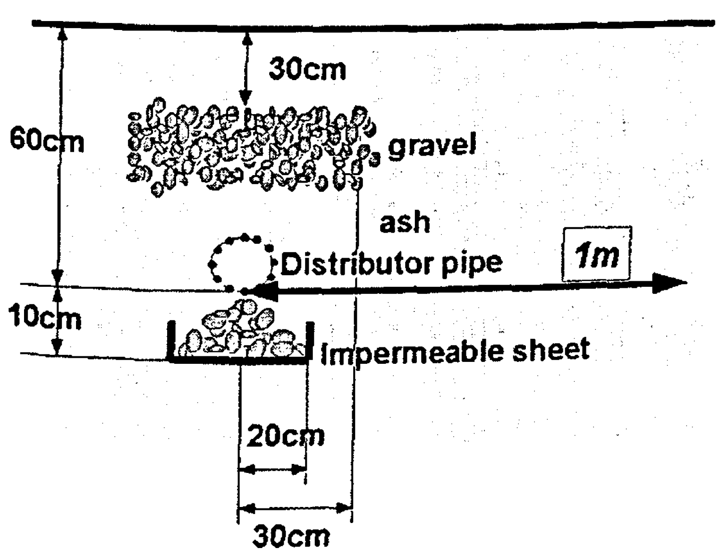
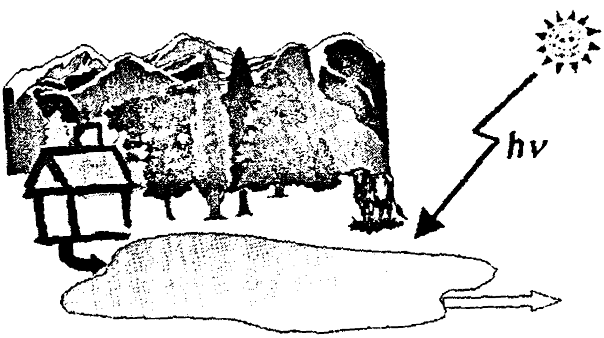


Figure 5. Cross-section of a typical soil infiltration unit.

D. Oxidation Pond Treatment

An oxidation pond utilizes active biomass to treat wastewater in the presence of nutrients and solar energy.



$$BOD + O_2 \Rightarrow \text{biomass} + CO_2$$

$$CO_2 + \text{nutrient} + h\nu \Rightarrow \text{Algae} + O_2$$

Figure 6. Schematic illustration of an oxidation pond treatment

E. Zero Emissions System

The concept of zero emission material cycles is based on the concept that the total material cycle in the anthropogenic sphere should be clarified and managed as an integrated/holistic system. It would be necessary that the residence times of materials and resources in the anthropogenic sphere are maximized. This means that intake of natural resources is within the renewable limits and the final emission to the environment is within the assimilable limits.

Integrated zero emissions systems combine natural ecosystems and anthropogenic activities into a stable network system. Such an example of Integrated Biomass System (IBS) has been developed in Fiji on experimental basis. The experiment, which started in 1998, is designed by Dr. George Chan and is supported by the United Nations University. Figure 7 schematically shows the process of IBS, as it is developed in Fiji.

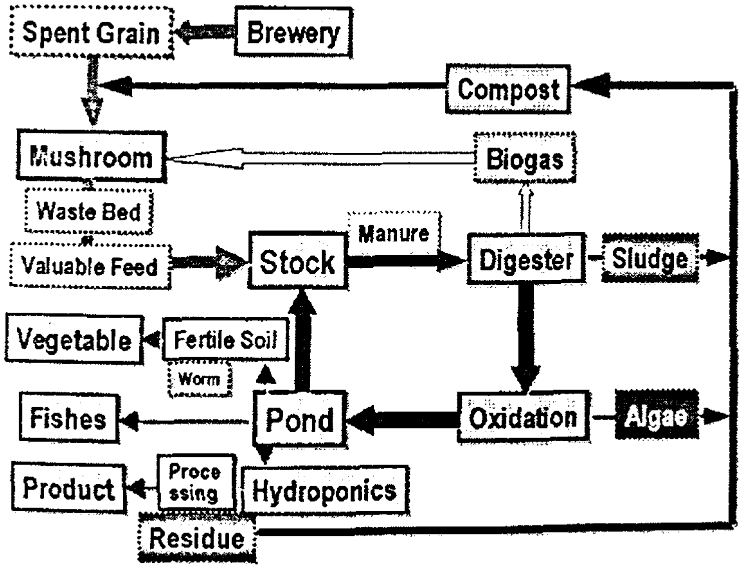


Figure 7. A schematic description of the integrated biomass system in Fiji.

Conclusions

1. Holistic or integrated approaches should be adopted for wastewater treatment and re-use. These should include consideration of a long-term material and energy balance in order to assess their sustainability.
2. Development of sustainable technologies should be based on physical, climatological, social and cultural conditions of a local site.
3. Treatment of wastes with some kind of value-added output are necessary.

8

Coping with Increased Water Scarcity in Dry Areas:
Increased Water Productivity

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Overview

The increasing scarcity of water in the dry areas is now a well-recognized problem. High rate of population growth and development, require continuous diversion of agricultural water to higher priority sectors. The need to produce more food with less water poses enormous challenges to transfer existing supplies, encourage more efficient use and promote natural resources conservation. On-farm water-use efficient techniques if coupled with improved irrigation management options, better crop selection and appropriate cultural practices, genetic make-up, and timely socio-economic interventions would help achieving this objective.
In water-scarce areas, water is more limiting to production than land hence maximizing water productivity, should have higher priority over maximizing yield in the strategies of water management. Conventional guidelines for determining crop irrigation requirements, which are designed to maximize yield, need to be revised for achieving maximum water productivity. In a fast changing world towards free trade and open markets, future trends in water and land use in agriculture are difficult to predict. However, under such conditions, planning water- and land-use should be based on the comparative advantages of the dry areas, but within the framework of maximizing the return from the limited available water resources.

If agricultural production and livelihoods in the dry areas are to be sustained, even at current levels, greater priority must be given to improving water productivity and enhancing the efficiency of water procurement.

Background

The dry areas of West Asia and North Africa (WANA) are characterized by low rainfall with limited renewable water resources. The share of the dry areas of the world's available fresh water is very small. Renewable water resources in WANA is about 1250 m^3 per capita, compared to about 7,420 m^3 for the world and 15,000, 20,000 and 23,000 m^3 per capita for Europe, North America, and Latin America, respectively (World Resources Institute, 1999). In many countries of the Middle East, available water will barely satisfy basic human needs in this century (The World Bank 1994).

The demand for water continues to grow in these areas with the fast human population growth and improved standard of living. Presently, over 75% of the available water in the dry areas is used for agriculture. However, competition for water among various sectors deprives agriculture of substantial amounts every year. In the dry areas most of the hydrological systems are already stretched to the limit, yet more food production is required every year. Such an objective may not be attained without substantially increasing the efficiency with which available water resources are used (Tribe, 1994). To maintain, even the current levels of agricultural production and environmental protection needs, greater efforts should be made to enhance the efficiency of water procurement and utilization. Increasing water productivity in dry areas becomes a vital issue were we must "produce more out of less water".

This theme poses enormous challenges to allocate existing supplies, encourage more efficient use and promote natural resources conservation. A vast array of economic, social, legal, political and other institutional factors affect both, the perception of and the response to, water management induced problems. All such factors cannot be considered in isolation. Responses require an understanding of the complex interactions that occur between social, political and physical components.

This paper discusses some of the prospects for addressing the problem of increasing water scarcity in the dry areas. It emphasizes, although not restricted to, ICARDA's experience in developing promising packages of technologies for improved on-farm water management and crops that are more water-use efficient. The paper addresses the conditions prevailing in the dry areas and particularly in West Asia and North Africa (WANA) were ICARDA has extensive experience.

Terms and definitions

Water-use Efficiency (WUE): The term is used here to indicate the ratio of crop biomass production to the water consumed by the crop.

Water may be consumed in evaporation, transpiration and/or quality deterioration.

Consumed water: The lost water is the portion of irrigation water that has left the farm and is unrecoverable at the basin level. Some of the water, which is conventionally considered as water losses at the farm, such as deep percolation and surface runoff, is completely or partially recoverable downstream and may not be considered an absolute loss. Absolute losses include evaporation, transpiration and the reduction in water quality, which limits its use.

Water Productivity (WP): This term is introduced to remove the confusion arises from the misuse of the term "water use efficiency", which may indicate different meanings. In this paper it is also used to mean, "water use efficiency" as defined earlier and both terms are used in this paper interchangeably.

Supplemental Irrigation (SI): The application of a limited amount of water to rain-fed crops that can normally grow without irrigation, to increase and stabilize production. This is different from conventional full irrigation, which is applied in areas having very low rainfall where no economical crop production can be achieved without irrigation.

Water Harvesting (WH): The term implies the concentration of low rainfall, which is not enough to support sustainable agricultural production, from larger area (the catchment), into a smaller area (target), where increased available moisture can support economical production. The process implies depriving part of the land from some or most of its share of rainfall for the sake of another part to be added, through runoff, to its original share of rainfall. Thus, universally water harvesting may be defined as: "the concentration of rainfall, through runoff, for beneficial use". Beneficial use can be agricultural, domestic, industrial, and/or environmental.

Increasing Water Productivity

Many factors and variables influence the relation between crop production and water, some of which remain to be known. According to current knowledge, factors affecting water productivity can be broadly categorized in four groups: climate, soil, crop and management. There are numerous interactions among factors within any group and/or among groups. High water productivity may be achieved through applying the following approaches:

A. promoting water-use efficient techniques;
B. adopting efficient on-farm water management;
C. selecting proper cropping pattern and cultural practices; and
D. developing more efficient crop varieties.

Each one of these is discussed in greater detail in the following sections.

A. Promoting Water-Use Efficient Techniques

In dry areas, moisture availability to the growing crops is the most significant single factor limiting production. It seems logical that considerations of this production factor must therefore receive high priority. Technologies for improving yield, stabilizing production and providing conditions suitable for using higher technology are important, not only for improved yields but also, for better water productivity. Yields and water productivity are substantially improved, in Mediterranean-type climate, with the application of supplemental irrigation in the rainfed areas, the adoption of water harvesting in the steppe areas and the use of improved irrigation systems in irrigated areas.

Supplemental Irrigation for Rainfed Farming:
The rainfed areas occupy an important role in the production of food in many countries of the region and the world. They cover more than 80% of the land area used for cropping throughout the world and produce some 60% of the total production (Harris et al., 1991). In the Mediterranean-type climate, rainfall is characterized by its variability both in space and time. In general, rainfall amounts in this zone are lower than seasonal crop water requirements; moreover its distribution is rarely in a pattern that satisfies the crop needs for water. Periods of sever moisture stress are very common and in most of the locations these coincide with the stages of growth that are most sensitive to moisture stress. Soil moisture shortages at some stages cause very low yields. Average

wheat grain yields in WANA range between 0.6 and 1.5 t/ha depending on the amount and distribution of seasonal precipitation.

It was found, however, that yields and water productivity are greatly enhanced by the conjunctive use of rainfall and limited irrigation water. Research results from ICARDA and others, as well as harvest from farmers, showed substantial increases in crop yield in response to the application of relatively small amounts of supplemental irrigation. This increase covers areas having low as well as high annual rainfall. Table 1 shows substantial increases in wheat grain yields under low, average, and high rainfall in northern Syria, with application of limited amounts of supplemental irrigation. Applying 212, 150, and 75mm of additional water to rainfed crop increased yields by 350, 140, and 30% over that of rainfed receiving annual rainfall of 234, 316, and 504mm respectively. In addition to yield increases, SI also stabilized wheat production from year to the other. The coefficient of variation was reduced from 100% to 20% in rainfed fields that adopted supplemental irrigation.

Table 1. Yield and water productivity for wheat grains under rainfed and supplemental irrigation in dry, average and wet seasons at Tel Hadya, North Syria (Oweis 1997)

Season/Annual Rainfall (mm)	Rainfed yield (t/ha)	Rainfall WUE (kg /m^3)	Irrigation amount (mm)	Total yield (t/ha)	Yield increase due to SI (t/ha)	SI WUE kg/m^3
Dry (234mm)	0.74	0.32	212	3.38	3.10	1.46
Average (316mm)	2.30	0.73	150	5.60	3.30	2.20
Wet (504mm)	5.00	0.99	75	6.44	1.44	1.92

The impact of SI is not only on yield, but also more importantly on water productivity. Both the productivity of irrigation water and that of rainwater are improved when both are used conjunctively. Average rainwater productivity in the dry areas is about 0.35 kg/m^3. However, it may be increased to as high as 1.0 kg/m^3 with improved management and favorable rainfall distribution (see Figure 1). It was found that a cubic meter of water applied at the proper time might produce more than 2.0 kg of wheat grain over that using only rainfall. The high water productivity of supplemental irrigation water is mainly attributed to alleviating moisture stress during the most sensitive stages of crop growth. Moisture stress during wheat flowering and grain filling usually cause a collapse in the crop seed filling and reduce the yields substantially. When SI water is applied before the occurrence of stresses the plant may produce its potential.

Furthermore, using irrigation water conjunctively with rain was found to produce more wheat per unit of water than if used alone in fully irrigated areas where rainfall is negligible. In fully irrigated areas wheat yield under improved management is about 6.0 t/ha using about 800 m3/ha of irrigation water. Water productivity the will be about 0.75 kg/m^3, one third of that achieved with supplemental irrigation. This difference should encourage allocation of limited water resources to the more efficient practice (Oweis 1997).

Water harvesting for drier environment

The drier environments of WANA or as they are so-called badia or steppe cover most of this region. The steppe receives inadequate annual rainfall for economical dry farming production. The distribution and intensity are also sub-optimal. The limited rainfall comes in unpredictable sporadic storms often with high intensity. When often it falls on crusted soils with low infiltration rate, runoff occurs and water flows to other areas depriving the land of its share of rainfall. Therefore, rainfall in this zone is largely lost back to the atmosphere as evaporation. Research has shown that in the eastern Mediterranean dry region, only less than 5% of the rainfall is used by already poor range and even lesser percentage joins the ground water (Oweis and Taimeh 1996). Frequent dry periods occur during the growing season causing severe moisture stress and plant failure in most of the years. Unfavorable rainfall characteristics, poor vegetative cover, soil surface conditions, and the absence of proper management are the major causes for the loss of rainwater. Consequently, desertification occurs in this environment at an alarming rate and migration of people to the urban areas is one of the characteristics of these areas, (Oweis et al 1999).

Through the history, water harvesting has shown good potential in increasing the efficiency of rainwater by concentrating it through runoff to ensure enough moisture in the root zone of the plants.

Indigenous systems such as jessour and miskat in Tunisia, tabia in Libya, cisterns in north Egypt, hafaer in Jordan, Syria and Sudan and many other techniques are still in use (Prinz, 1994). Unfavorable socio-economic conditions over the last decades has caused decline in the use of these systems, but recently the increased water scarcity dry areas is favoring the revival of these systems.

Small basin micro catchments in the Muaqqar area of Jordan have supported almond trees now for over 15 years without irrigation in an area with 125 mm annual rainfall. In the same area where annual rainfall may drop to less than 80 mm small farm reservoirs were able to collect water every year with amounts enough to justify economical agricultural development (Oweis and Taimeh 1996). In ICARDA's on-farm water husbandry in WANA project, significant results have already been reported. In Mehasseh in Syria (120 mm annual rainfall) the shrubs having less than 10% survival rate grew under micro-catchments with over 90% survival rate. In the northwest Egypt (130 mm annual rainfall) the same project has shown that small water harvesting basins with 200 m^2 catchment can support olive trees and that harvesting rainwater from greenhouses can provide about 50% of the water required by vegetables grown within it (Oweis et al 2001).

These experiences and many others show that the productivity of rain in the drier environments can be substantially increased when a proper water harvesting technique is implemented. This is especially true because at the present time very little of this rain is productive. At the large scale, ICARDA has developed methodology for using remotely sensed data and ground information in a GIS framework to identify suitable areas for water harvesting and appropriate methods for the prevailing conditions (Oweis et al, 1998). It was estimated that 30-50% of the rain in this environment might be utilized if water harvesting is practiced. This development will increase the current rainwater efficiency several times.

Efficient irrigation systems

Three main irrigation methods are used in practice; surface irrigation methods including basins, furrows and boarder strips, sprinkler irrigation methods including set systems, travelling guns and continuous move systems and trickle irrigation methods with drip, micro-sprinklers and subsurface systems. These systems greatly vary in their application, distribution and storage efficiencies. However, most of the losses associated with these efficiencies are totally or partially recoverable either at the farm level or at the basin level. For example, deep percolation losses in furrow irrigation may join ground water or are recovered in the drainage system. Also runoff losses may be recycled in the same farm or be used by downstream farmers. The absolute losses due to irrigation systems are those that may not be recovered, such as evaporation and deterioration in quality. For example; greater evaporation losses are common in surface irrigation over that in trickle irrigation.

The contribution of irrigation systems to improved water productivity is not limited to minimizing unrecoverable losses. The role of the system in making water more available in amount and timing for plant growth has great effect on water productivity (Pereira, 1999). For example; drip irrigation allows more frequent irrigation ensuring no crop water stress between irrigation applications as the case with surface irrigation, since it is not economical to irrigate more frequently with the later. The flexibility in the system to apply chemicals uniformly during irrigation and the role in controlling, or encouraging, diseases and pests can affect water productivity. Sprinkler irrigation creates favorable humid microclimate in wheat fields encouraging rusts, which can in turn reduces water productivity.

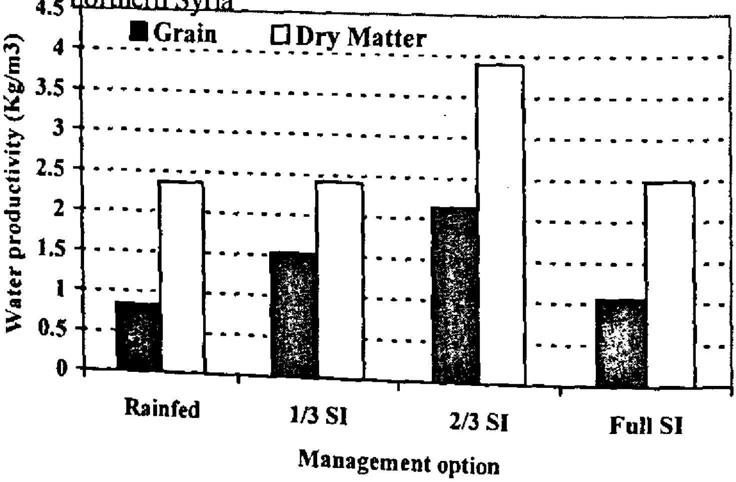
B. Adopting efficient on-farm water management

Deficit irrigation

Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (English et al. 1990). The adoption of deficit irrigation implies appropriate knowledge of crop water use and responses to water deficits, including the identification of critical crop growth periods, and of the economic impacts of yield reduction strategies. Figure 2 Shows typical results on wheat, obtained from field trials conducted in a Mediterranean climate in northern Syria. The results show significant improvement in SI water productivity at lower application rates than at full irrigation.

Highest water productivity of applied water was obtained at rates between 1/3 and 2/3 of full SI requirements, in addition to rainfall. Application of nitrogen improved water productivity, but at deficit SI lower nitrogen levels were needed (see Figure 3). This shows that under deficit irrigation practice other cultural practices may need to be adjusted. Planting dates, for example, interact significantly with the level of irrigation applied. Optimum levels of irrigation to maximize water productivity need to consider all these factors. (Oweis et al 1998)

Figure 1. Water productivity of wheat as effected by the amount of supplemental irrigation in northern Syria



The water productivity indicator defined above is useful to identify the best irrigation scheduling strategies for deficit SI of cereals (Zhang and Oweis, 1999), to analyze the water saving performance of irrigation systems and respective management (Ayars et al., 1999), and to compare different irrigation systems, including for deficit irrigation. Experience from Syria showed that applying only 50% of the rainfed wheat SI requirements reduces yield by only less than 15%.

Strategies for optimal deficit SI in rainfed areas involves rainfall amounts and distribution in addition to the sensitivity of crop various growth stages to moisture stress. Zhang and Oweis 1998, have developed and used a quadratic wheat production functions to determine the levels of irrigation water for maximizing yield, net profit, and the levels to which the crop be under-irrigated without reducing income below that which would be earned for full irrigation under limited water resources (see Table 2). The analysis suggests that irrigation strategies to maximize crop yield and/or net profit under limited land resources should not be recommended. On the other hand, the analysis shows that for sustainable utilization of limited water resources and higher water productivity a sound strategy would involve maximizing profit.

Table 2. Estimated amount (mm) and timing of supplemental irrigation for maximizing yield, maximizing the net profit and a targeted yield under different rainfall conditions

Rainfall	W_m[a]	W_1[b]	W_w[c]	W_{cw}[d]	W_t[e]	Time of irrigation
Bread						**Stem elongation,**
wheat						**booting, and grain filling**
250	430	336	260	161	158-254	Stem elongation, flowering
300	380	286	210	111	108-204	and/or grain filling
350	330	236	160	61	58-155	Flowering and/or grain
400	280	186	110	11	0-144	filling
450	230	136	60	0	0-55	Grain filling
						Grain filling
Durum						
wheat						**Stem elongation,**
250	510	454	314	180	144-207	**booting, and grain filling**
300	460	404	294	130	94-157	*Stem elongation, flowering*
350	410	354	244	80	44-107	and/or grain filling
400	360	304	194	30	0-57	Flowering and/or grain
450	310	254	144	0	0	filling
						Grain filling

[a] Amount of water required for maximizing grain yield.
[b] Amount of water required for maximizing the net profit under limited land resources.
[c] Amount of water required for maximizing the net profit under limited land resources.
[d] Amount of water required for deficit irrigation at which the net profit equals that at full irrigation under limited water resources.
[e] Amount of water required for targeted yield of 4-5 t ha^{-1}.

The decision on optimal strategies under varying conditions is a complex one. Especially in rainfed areas where rainfall is varying in amount and distribution. For example, it was found that spreading out dated of sowing of rainfed wheat over the three months of November to January substantially reduces the peak water demand during the SI period in the spring (Oweis and

Hachum, 2001). This reduction is improved when deficit irrigation is applied. Analysis was conducted using simplified optimization model solved by linear programming and used 4-year data (1992-1996) from field experimental research conducted on wheat in northern Syria. The results of the analysis showed that a multi-sowing date strategy has reduced the peak farm water demand rate by more than 20%, thus potentially reducing irrigation system capacity and/or size. Also, the water demand rate of a larger area can be met with the same water supply. However, optimal sowing dates that minimize farm water demand rate do not always maximize total farm production and/or water productivity. The outcome depends on crop water requirements and yield for each sowing date. Furthermore, this selection is greatly influenced by the level of water scarcity.

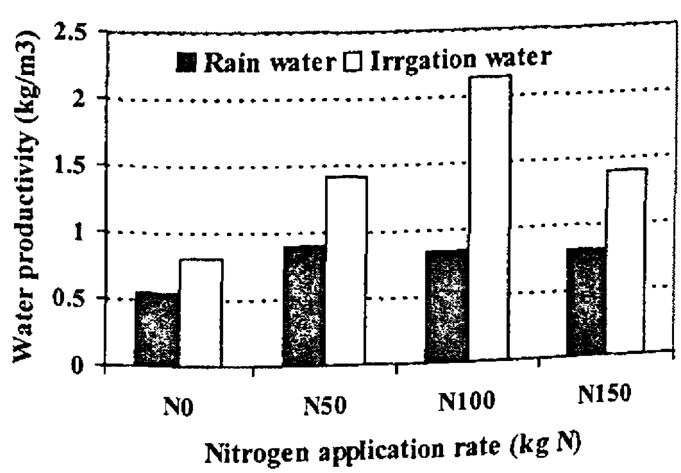
C. Selecting Proper Cropping Pattern and Cultural Practices

Research has shown that good soil and crop management practices can considerably increase the efficiency with which water available from precipitation and irrigation be used. Improved water productivity can be gained if crops are well established and adequately fertilized, weeds are controlled, and appropriate crop rotations are used (Pala and Studer 1999). These activities should also be considered together with the proper management of the soil if productivity is to be sustained and resources to be conserved in the long term. Soils of the region are predominantly calcareous, frequently phosphate deficient with variable depth and texture determining the maximum amount of water that can be stored and hence the effective length of the growing season. Production improvements are optimized by new technologies that integrate improvements to crop uptake of water and nutrients. Within this context, innovations in soil and crop management are sought by agricultural scientists to make maximum use of water available for crop growth. This is mainly through increasing water supply to crops, increasing the transpiration by crops and decreasing evaporation from soil surface (Gregory, 1991). The suggested technology packages vary with agro-ecological conditions and farmer's objectives.

Improved fertility improves water use efficiency (Cooper, 1991) and can, therefore, improve and stabilize production in rainfed areas and enable crops to exploit favorable rainfall in good years. Given the inherent low fertility of many dry-area soils, judicious use of fertilizer is particularly important. Extensive work in Syria (Pala et al., 1996), demonstrated the benefits of appropriate fertilization on water-use efficiency and therefore on production and yield stability especially of wheat and barley, in WANA. In deficient soils, seedbed phosphate (usually together with a small dose of nitrogen) enhances the rate of leaf expansion, tillering, root growth, and phenological development, ensuring more rapid ground cover and canopy closure, and earlier completion of the growth cycle before rising temperatures increase the atmospheric demand (Gregory, 1991).

With availability of irrigation water, the role of fertilizers, particularly nitrogen, in improving water productivity is very obvious in areas where nitrogen is very deficient. Extensive work on SI at ICARDA has shown that using additional 50 kg of nitrogen per hectare may double water productivity. However, the optimum levels of nitrogen vary with soil nutrient level and the amount of irrigation given (see Figure 2) and need to be determined at the site.

Figure 2. Water productivity of wheat as effected by the rate of nitrogen application under ranfed and supplemental irrigation in northern Syria (Oweis 1997)



D. Developing More Efficient Crop Varieties

Exploitation of the interaction of genotype and management

The identification of appropriate crops and cultivars with optimum physiology, morphology, and phenology to match local environmental conditions and, especially, the pattern of water availability is one of the important areas of research within the cropping systems management for improved water use efficiency. Breeding and selection for improved water use efficiency, and the use of genotypes best adapted to specific conditions can improve soil water use and increase water productivity (Studer and Erskine 1999).

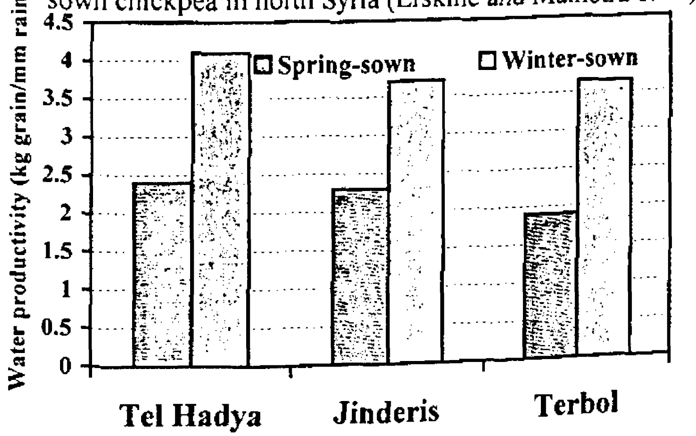
An important approach to increase the efficiency of water use is to change both management practices and cultivar concurrently. This allows a quantum jump in crop and water productivity. Seasonal shifting, i.e. the development of crop varieties that can be grown in winter under lower evaporative demand, represents an additional challenge for breeders aiming at using scarce water more efficiently, since traits such as winter hardiness and disease resistance of the cultivars have to be improved. The development of crop varieties for early growth vigor has been a major concern of winter cereal breeders in WANA for many years (Ceccarelli et al., 1991). Early and complete canopy establishment to shade the soil and reduce evaporative loss from the soil surface can significantly improve water productivity of rainfed crops in Mediterranean conditions and also, apparently, of summer-rainfall crops over much of the semi-arid tropics. The following two case histories illustrate this simultaneous change in both genotype and management with the first involving early sowing in the food legume chickpea and the second covering the use of supplemental irrigation on wheat.

Early Sowing of Chickpea

In the Mediterranean region rain falls predominantly in the cool winter months of November through March. Traditionally chickpea sowing is done in late February and early March. As a consequence the crop experiences increasingly strong radiation and a rapid rise in temperature from March onwards which causes the rate of leaf area development to increase with consequent high evapotranspiration. This period of high evaporative demand occurs at the end of the rainfall when the residual soil moisture is inadequate to meet the evaporative demand. The crop, therefore, experiences drought stress during late vegetative growth and reproductive growth and produces a low yield. The replacement of traditional spring sowing with winter is possible but only with cultivars possessing cold tolerance and resistance to a key fungal diseases (Studer and Erskine 1999).

The average gains in seed yield from early sowing chickpea over three sites and ten seasons is 70% or 690 kg/ha, which translates into an increase in water use efficiency of 70% (Figure 3) (Erskine and Malhotra 1997). In 30 on-farm trials comparing winter with spring chickpea in northern Syria, the mean advantage of winter sowing in seed yield and water use efficiency was 31% (Pala and Mazid 1982). Currently an estimated 150,000 ha of chickpea is winter-sown in the West Asia and North Africa region.

Figure 3. Rain water productivity in winter and spring-sown chickpea in north Syria (Erskine and Malhotra 1997)



Improved Cultivars Under Supplemental Irrigation

The use of supplemental irrigation is another example of a concurrent change in both management practice and water-responsive cultivars to increase water productivity. The example demonstrates the need to combine changes in management with the use of adapted varieties in SI of wheat. This practice requires varieties that are adapted or suitable to be used with varying amount of water application. The proper varieties need first to manifest a strong response to limited water applications, which means that they should have a relatively high yield potential. At the same time, they should maintain some degree of drought resistance, and hence express a good plasticity. In addition, the varieties should respond to higher fertilization rates that are generally required under SI (Oweis, 1997), and resist lodging, which can occur in traditional varieties under irrigation and fertilization.

Table 3. Average 4-years rainwater and supplemental irrigation (SI) water productivity for durum and bread wheat varieties grown in northern Syria. (Oweis, unpublished data)

Variety*	SI water productivity (kg/m^3)			Total water productivity (kg/m^3)
	Full SI	33% of full SI	67% of full SI	
Cham 1	0.809	1.050	2.426	1.244
Cham 3	1.008	0.943	1.303	1.097
Lahn	0.880	0.889	1.733	1.328
Omrabi 5	0.903	0.794	3.310	1.370
Gomam	0.929	0.903	0.717	1.394
Mexipak	0.769	0.601	0.808	1.000
Cham 4	0.976	0.952	1.647	1.374
Cham 6	1.048	0.845	0.927	1.106

* *Cham 1, Cham 3, Lahn, and Omrabi 5 are durum and Gomam, Mexipak, Cham 4 and Cham 6,are bread wheat.*

Water Productivity Versus Land Productivity

In conventional irrigation, water is applied to maximize crop yield (maximizing production per unit of land). This is the case when water is not limiting, rather when land is limiting. In the dry areas, land is not, any more, the most limiting factor to production rather water is increasingly becoming the limiting factor. It is, therefore, logical to conclude that since water is more limiting factor, then the objective should be maximized the return per unit of water not per unit of land. This should yield higher overall production, since the saved water can be used to irrigate new land with higher production. However, high water productivity does not come without high yield. Fortunately, both water productivity and yield increase at the same time as improvement to on-farm management is introduced. This parallel increase in yields and water productivity, however, does not continue all the way. At some high level of yield (production/unit of land) incremental yield increase requires higher amounts of water to achieve. This means that water productivity drops as yield increases above certain levels. Figure 4 shows the relation between yield increase and water productivity increase for durum wheat under supplemental irrigation in Syria.

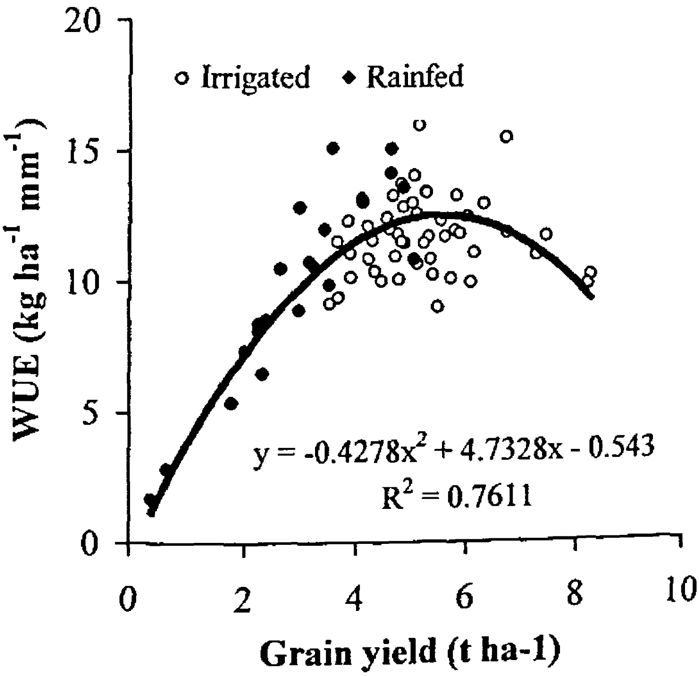


Figure 4. Relationship between crop water productivity and crop grain yield for durum wheat under supplemental irrigation in Syria (Oweis et al 1998).

It is clear that the amount of water required to produce the same amount of wheat at yield levels beyond 5 t/ha is very high compared to the requirements at lower levels. It would be more economical to produce only 5t/ha, then use the saved water to irrigate new land than to produce maximum yield with excessive amount of water at low water productivity. This is keeping in mind the assumption that water not land is limiting and that there is not sufficient water to irrigate the available land. Generally, maximum water productivity occurs at sub-optimal crop yield per unit area. This is provided the relation is not a straight line, which is not always the case.

The association of high WUE values with high yields has important implications for the crop management for achieving efficient use of water resources in water scarce areas (Oweis et al 1998). However, attaining higher yields with improved WUE should ensure that increased gains in crop yield are not offset by increased costs of inputs and running costs. The curvilinear WUE-yield relationship emphasizes the importance of attaining relative high yields for efficient use of water. A policy for maximizing yield and/or net profit should be looked at very carefully under water scarcity conditions. Guidelines for recommending irrigation schedules under normal water availability (Alan et al 1998) may need to be revised when applied in areas with limited water resources.

Case Study From Syria

ICARDA long-term research in Syria has shown that applying only 50% of full supplemental irrigation requirements (over that of rainfall) would cause a reduction in yield of only 10-15%. This finding, in light of the increasing water scarcity in Syria, have encouraged ICARDA and the Extension Department of the Ministry of Agriculture to test a deficit supplemental irrigation strategy at farmers fields.

The objective was improved farmer return and conserve water resources by improving water productivity under limited water resources. The hypothesis was that applying 50% of supplemental irrigation requirements to the whole field will, while maximizing water productivity, bring more benefits to the farmer than applying 100% of wheat irrigation requirements to half of the field, while the other half is left rainfed. The demonstrations were conducted at farmer's fields and managed collectively by the farmer, the researchers and the extension agents.

The farmer's managed demonstration plots were established over 6 years in the rainfed areas with annual rainfall ranges from 250 to 450 mm. Rainfed wheat yields in this area is generally low (less than 2 tons/ha) and variable from one year to the other. Supplemental irrigation is practiced in the area and has shown good potential to increase and stabilize production. However, it was observed that farmers tend to over irrigate and the ground water in the region has been continuously depleted.

Farmer's land was divided into four one-hectare parts: the first was left rainfed, the second was irrigated by the farmer, as he usually does, but water amounts was measured, the third was irrigated to ensure no moisture stress and the fourth part was irrigated with 50% of the full irrigation requirements. Water requirements were determined using evaporation from Class-A pan installed in the field using appropriate pan and crop coefficients. Rain was measured also at the farm. Irrigation water was given from wells or public canal and measured by calibrating the flow rate and determining the time needed to apply the required amount. At the end of the season the crop yields were measured and other data were collected. The farmers used improved wheat cultivars and recommended inputs and cultural practices at each site.

Under unlimited water resources the farmer has no incentive to save on irrigation water. In this case full crop water requirement is applied to produce maximum yield with lower water productivity. However, when water is not enough to provide full irrigation for the whole farm, the farmer has two options: to irrigate part of the farm with full irrigation leaving the other part rainfed or to apply deficit supplemental irrigation to the whole farm. With the assumption that under limited water resource only 50% of the full irrigation required by the farm is available the option of deficit irrigation was analysed in comparison to other options.

The results are summarized in Table 4. They show that under the rainfall conditions prevailed in Syria during the years 1994 to 2000, a farmer having 4-hectare farm would on average produce 33% more grain from his farm, if adopt deficit irrigation, than if applied a full irrigation strategy. The advantage of applying deficit irrigation increased the gain by over 50% from that of the farmer practice of over irrigation. Applying deficit supplemental irrigation strategy, when water resources are limited, will eventually double the land area under irrigation. The results of this program can well demonstrate the possibility of producing more with less water.

Table 4. Wheat grain production scenarios for 4-hectar farms with various strategies of supplemental irrigation in Syria.

Management strategy	Rainfed	Farmer's	Full SI	Deficit SI
Total water applied	342 mm	2980 m^3	2220 m^3	1110 m^3
Grain yield (t/ha)	1.8	4.18	4.46	4.15
Water productivity (kg/m^3)	0.53	0.70	1.06	1.85
Possible 4-ha farm production (ton) if water is not limiting	7.2	16.7	17.8	17.8
Possible 4-ha farm production (ton) under limited water (50% of full irrigation requirements is assumed available)	7.2	10.8	12.5	16.6

Conclusions

In the dry areas, where water scarcity is increasing, generally water, not land, is the most limiting resource. Under such conditions adopting irrigation strategies to maximize the return per unit of water i.e. increasing water productivity may have higher priority over that of maximizing yield per unit of land.

It is possible to substantially increase water productivity through adopting improved irrigation systems, applying sound irrigation management, growing improved crop cultivars and appropriate cropping patterns and cultural practices. It is however, important that these interventions be integrated with full participation of the farmer to develop viable strategies and efficient and sustainable production systems.

Guidelines for determining crop irrigation requirements to maximize water productivity are needed in water scarce areas. Furthermore, relations between water productivity and water used need to be developed for most of the crops in these areas.

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9

Agroclimatic Characterization for Water Management in Central Asia

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Overview

Agroclimatic characterization of the Central Asian republics is needed in order to understand the diversity of climatic conditions in this part of the world. In the context of the high priority given by governments in the region to crop diversification, it offers a rational basis for more effective targeting of improved crops, cultivars and adapted land use. In addition, it may help to save water.

A comprehensive agroecological characterization of the region has been initiated within the framework of the ADB-funded ICARDA Project "On-Farm Soil and Water Management in Central Asia". The characterization is currently carried out at two different scales, and involves the development of a GIS for the experimental sites (Boykozon in Uzbekhistan, Sorbulak in Kazakhstan), and the upscaling to the level of broad agroecologies through agroclimatic zoning. The ultimate objective of this assessment is to map the spatial extent and severity of specific climatic stresses, such as drought, cold and heat. At the same time the assessment will allow to map the regional variations in crop water requirements.

Assessing the regional water demand for crops is a major challenge, in view of the fact that actual data on water requirements are available for few stations only, and need to be supplemented with estimates based on climatic data. In addition this site-specific information is difficult to extrapolate due to differences in topography and location. In order to assess regional crop water demand a sequential approach is required, based on the spatialization of the potential evapotranspiration, and followed by the spatialization of crop coefficients.

Maps of monthly potential evapotranspiration calculated according to the Penman-Monteith method have been prepared from raw climatic data for stations in Kazakhstan and Uzbekhistan. The procedure used is based on the mathematical technique of thin-plate smoothing spline functions, using the digital terrain model GTOPO30, aggregated to a grid cell size of 2.5x2.5 km. First, surfaces were created for each climate parameter used in the Penman-Monteith equation (temperature, radiation, humidity and wind). In a second step these surfaces were combined in accordance with the equation. These digital maps were created with the ANUSPLIN software package, and Excel software to automate the process of climate surface generation.

The maps of potential evapotranspiration will be used in combination with maps of crop coefficient values for each month to assess crop water requirements for individual crops. These studies of regional water demand may help decision-makers to target irrigation projects towards areas where crop water demand is lower, and make recommendations for irrigation that will be more site-specific than is currently the case.

Introduction

The Central Asian republics have a tremendous diversity in climatic conditions, spanning a wide range across rainfall and temperature gradients. It is a region where climatic extremes are very pronounced and where drought, very high and very low temperatures are taken for granted. This diversity of climate has been one of the key determinants of land use systems and their productivity. Another determinant is the general prevalence of relatively short growing periods, limited by both moisture availability and temperature (see Figure1).

Figure 1 indicates how at Fergana, Uzbekhistan, periods of moisture availability (winter and spring) mismatch with periods that temperature is adequate (spring and autumn). As a result the times of the year that both temperature and moisture are adequate for crop growth are limited to relatively short periods in autumn and spring. This is the most common situation in Central Asia.

In the former Soviet Union there was little differentiation in land use systems within broadly defined eco-regions, such as lowland rainfed agriculture, lowland irrigated agriculture, lowland semi-arid rangelands, and mountains (with extensive grazing on mountain pastures and irrigated crops in valleys). In the previous agricultural sector context the land management units were of such extent that they required little knowledge about the climatic variations at smaller scales. Accordingly there was little need to have detailed maps of agroclimatic conditions and the latter were therefore of a fairly general nature.

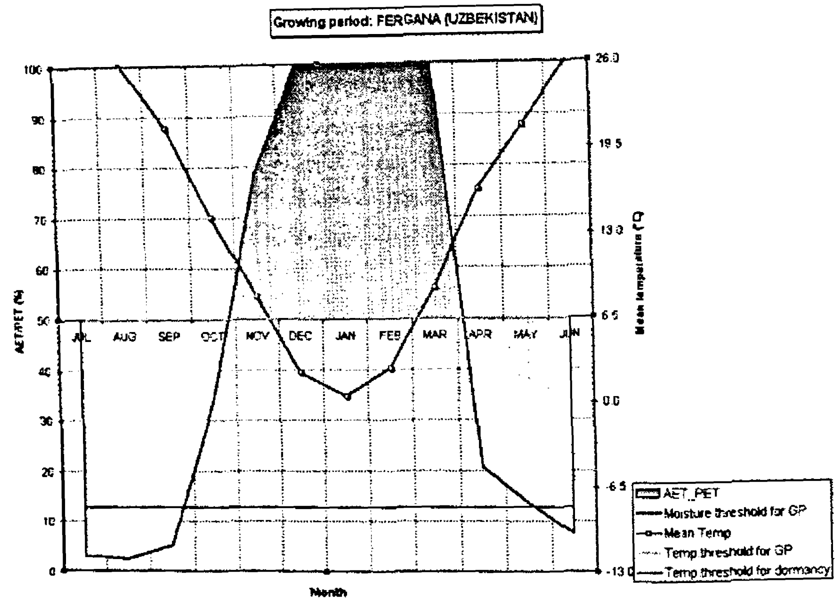

Figure 1. The climatic growing period at Fergana, Uzbekistan, as determined by temperature and water balance.

With the collapse of trade within the former Soviet Union, the governments of the Central Asian republics found themselves in a situation where a higher priority had to be given to food self-sufficiency and increase of agricultural production. At the same time the privatization of previously collective farms resulted into smaller land management units and the development of new farming systems.

To maintain or enhance productivity on these smaller farms, a better knowledge of the agricultural environments at a higher resolution is vital to guide diversification of land use and agricultural research efforts. In this context agroecological characterization is a key strategy component for enhancing the productivity of the newly developing agricultural systems in the region and for increasing water use efficiency.

Need for Agroclimatic Characterization

Currently the region has small-scale maps of the main climatic variables (rainfall, temperature, radiation etc.). While useful, these maps contain little detail and are therefore of limited value in guiding crop diversification. In addition, the maps do not take account of variations in topography that may occur within broad climatic regimes. Therefore they often fail to detect the interactions between weather and landforms, which can be particularly substantial in the case of temperature, rainfall and radiation, especially in hilly and mountainous areas.

A further limitation is that the climate parameters are, with exceptions, not integrated into derived variables that would be of more practical value for agricultural purposes, such as waterbalance, length and time of growing season, crop water requirements, risk of climatic stresses (drought, high temperatures, frost). A final complication is that such maps, when digitized and incorporated in a geographical information system (GIS), show areas within contours as entirely homogeneous, which is not realistic.

Given recent advances in spatial interpolation techniques, it is now possible to create computer-generated maps of individual climatic parameters, directly obtained from meteorological stations, that are more accurate than existing digitized maps and take better account of topography as a factor that influences climatic conditions. These maps can be combined in a GIS-system to produce, through modeling techniques, new maps of derived agroclimatic variables, which are more useful for land use and crop management recommendations.

These maps can assist research on germplasm enhancement. They will allow to identify the geographical distribution of major climatic stresses (heat, cold, and drought), to recognize areas that are susceptible to weather-induced pests and diseases and to distinguish environments where newly bred or introduced crop varieties are likely to perform well. The determination of crop water requirements on a regional basis allows to conserve scarce irrigation water and to compare different land use systems in terms of water use efficiency. Improved agroclimatic maps will also help research planning through the identification of sites that are representative for major agroclimates.

Agroclimatic Characterization for Assessing Regional Variations in Crop Water Requirements

One specific output of an agroclimatic characterization is the assessment of regional water demand as determined by climatic conditions. Up to now it has been assumed that the calculation of water requirements at a few research stations is sufficient to give realistic recommendations to farmers and irrigation scheme regulators in the whole of Central Asia on how much water to apply. In reality, water requirements are difficult to extrapolate due to differences in topography (altitude, slope, aspect) and location (latitude, continental or oceanic influences). As a result current guidelines on water application in Central Asia are very much based on generic figures that do not take account of local terrain and climatic conditions, are not very crop-specific, and, if applied strictly, may result in either under- or over-irrigation.

This study explains an approach, based on spatial statistics, which allows fine-tuning the estimates of water requirements, taking account of spatial variations in climatic conditions and producing continuous surfaces of water requirements.

Methodology and results

A comprehensive agroecological characterization of the region has been initiated within the framework of the ADB-funded ICARDA Project "On-Farm Soil and Water Management in Central Asia". The characterization is carried out at two different scales, and involves the development of a GIS for the experimental sites (Boykozon in Uzbekhistan, Sorbulak in Kazakhstan), and the upscaling to the level of broad agroecologies through agroclimatic zoning.

For 53 stations in Uzbekhistan and 123 stations in Kazakhstan quality-controlled data have been compiled of climatic normals, which include the parameters rainfall, maximum and minimum temperature, sunshine duration, relative humidity and wind speed. The stations are well distributed across the two countries (see

Figure 2) and the data are adequate to calculate potential evapotranspiration according to the Penman-Monteith method (Allen et al., 1998).

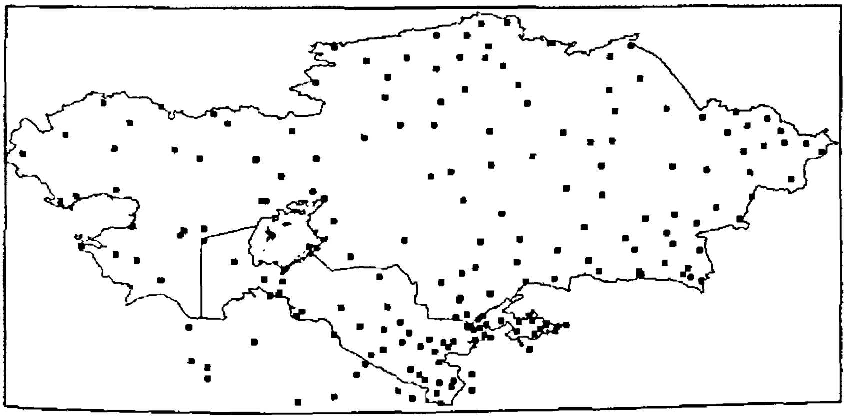

Figure 2. Location of meteorological stations used in the study

A 4-step approach is being followed for the assessment of climatically determined water demand:

> Step 1: selection of appropriate method for calculating reference water demand
> Step 2: regionalization of reference water demand (PET)
> Step 3: transition from reference water demand to crop water demand (CWR)
> Step 4: regionalization of crop water demand

Calculation of reference water demand
The reference water demand or potential evapotranspiration is the evapotranspiration from a reference crop (grass) under conditions of no moisture or nutrient stress. As a standard method for calculating the reference water demand, the Penman-Monteith formula has been widely accepted.

In comparison to previous methods used in Central Asia the Penman-Monteith approach has several advantages. First of all, it has been found to be the best performing prediction equation (Smith et al. 1990, Choisnel et al., 1992). It can be used for different time intervals, ranging from a month to an hour. This is a significant advantage for correlating short-term values obtained from automatic weather stations with longer-term values from established climate stations. The method is also suitable for all ecological conditions (Smith et al., 1990).

Regionalization of Reference Water Demand

The approach used for the regionalization of the reference water demand is based on spatial interpolation of the climate parameters used in the Penman-Monteith formula (maximum and minimum temperature, relative humidity, sunshine or radiation, and wind speed), followed by their combination into PET estimates on a spatial basis. This approach is outlined in Figures 3, 4 and 5.

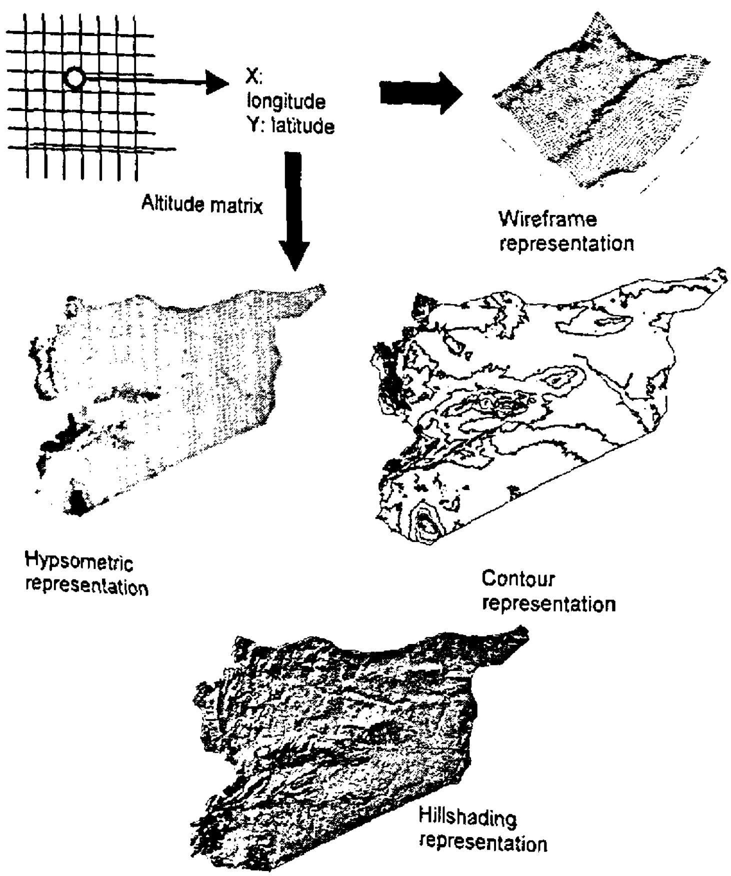

Figure 3. From altitude matrix to different representations of topography

The spatialization approach starts with the incorporation of a digital elevation model (DEM). The DEM is a grid file in which for each grid cell location the altitude is specified. The DEM is thus essentially an altitude matrix from which different terrain characteristics can be derived (slope, aspect, altitude, drainage), and that can be represented in different forms in GIS software (Figure 3). The next step is the actual spatialization, which links the DEM with the database that contains the climatic data. The rationale for linking climatic data with topography is that cclimatic variables, especially temperature, are strongly influenced by site altitude and other features of the surrounding terrain.

The spatial interpolation method is based on the mathematical technique of thin-plate smoothing spline functions and is topography-guided using a digital elevation model with 1 km resolution. As DEM the country sets clipped from the global DEM with 1 km resolution GTOPO30 have been used (EROS Data Center, 1998). The main advantage of a topography-guided interpolation is that they permit the use of terrain variables as auxiliary variables in the interpolation process. In contrast to the climatic target variables themselves, which are only known for a limited number of sample points, terrain variables have the advantage to be known for all locations in between, which increases the precision of the interpolated climatic variables significantly.

As a main tool, the spatialization software ANUSPLIN has been used. To accommodate the memory constraints of the software, the DEM has been aggregated to a grid cell size of 2.5 x 2.5 km. For each month and climate parameter (maximum and minimum temperature, sunshine duration, relative humidity and wind speed) surfaces have been generated for both Kazakhstan and Uzbekhistan. In order to automate the process of climate surface generation Excel software was written which links a user control module with the actual ANUSPLIN software.

This step is illustrated in Figure 4, which shows the generation of the annual rainfall map for Uzbekhistan.

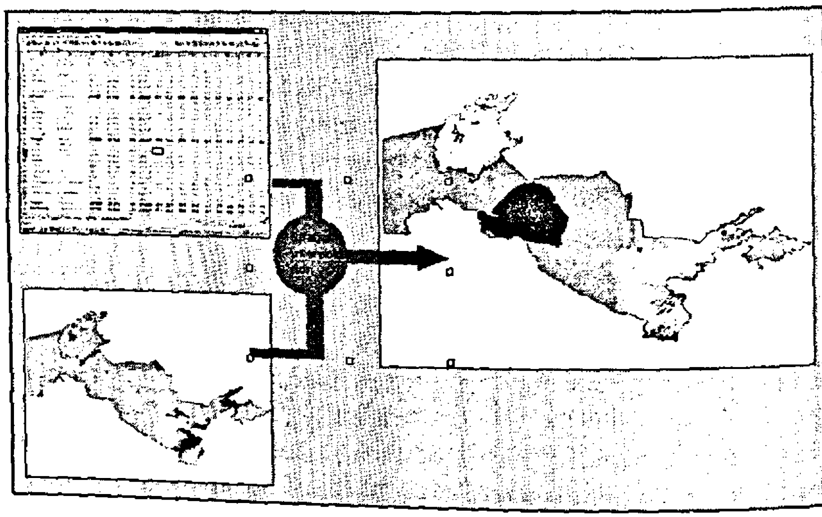

Figure 4. Generation of average annual rainfall map for Uzbekhistan

The next step is the generation of monthly potential evapotranspiration surfaces by combining the individual climate parameter surfaces according to the Penman-Monteith formula (Figure 5).

The resulting PET surfaces for Uzbekhistan are shown in Figure 6.

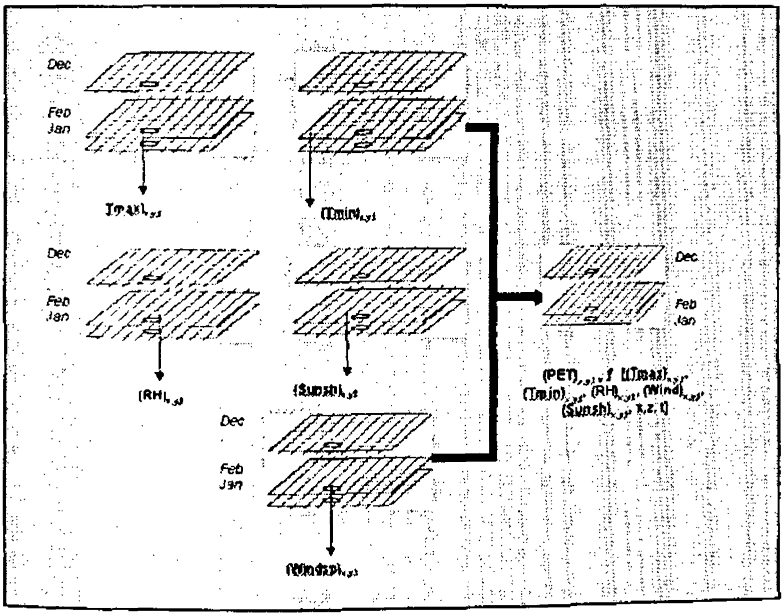

Figure 5. Generating PET surfaces from basic climate parameter surfaces

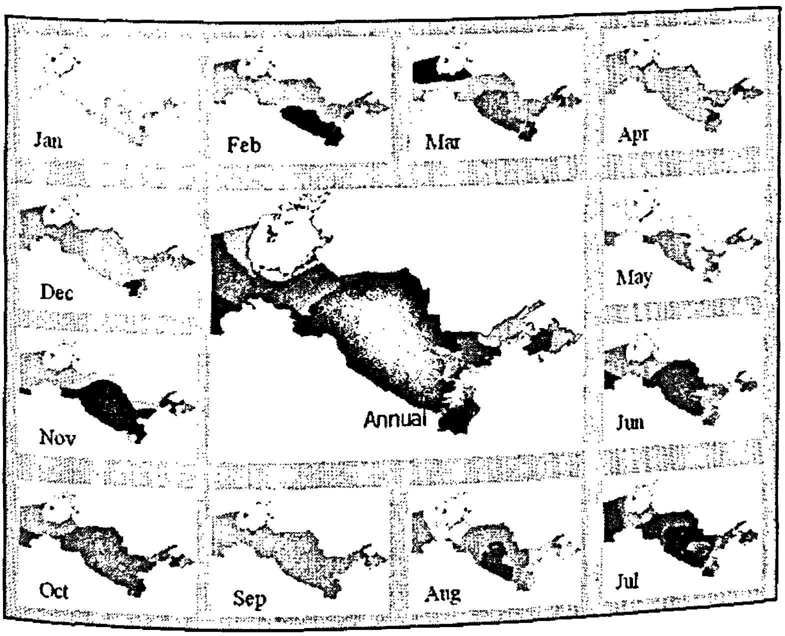

Figure 6. Generated monthly and annual surfaces of potential evapotranspiration for Uzbekhistan

Future work

The PET surfaces generated will be used as a basis for the determination of the water requirements for individual crops in the Central Asian countries. To this effect the well-known and simple methodology of Doorenbos and Pruitt (1984) will be followed, which links crop water requirements to PET through the use of crop- and calendar-specific crop coefficients.

$$CWR_t = kc_t \times PET_t$$

where,
CWR_t: crop water requirement at time t
kc_t: crop coefficient at time t

The crop coefficients express the effect of individual crop characteristics such as resistance to transpiration, crop height, architecture, reflection, ground cover, and of the growth stage. They can be obtained either from standard tables (e.g. Doorenbos and Pruitt, 1984) or obtained from lysimeter studies at experimental stations. In a final step the crop water demand will be spatialized. For the purpose of spatialization, it is important to note that at any particular site the crop coefficients can be represented as an array, of which the value depends on the time within the growth cycle. This type of array can be combined directly with the PET surfaces to generate surfaces of crop water requirements, if the particular crop is grown at the same time throughout the area covered by the surface. In such cases the array can be considered a site-independent constant, and the site-specific variation will only depend on PET.

However, if in the area studied the crop is planted at different times, the crop coefficients will also have a spatial variation. This variation will require the establishment of temporal grid files of crop coefficients as well as for PET. Also if the same crop has a different growth cycle in different places, the crop coefficients can no longer be considered constant across space. This is a very typical situation in areas with mountains and valleys. On higher altitude the length of the crop cycle increases, which results in different crop coefficients for the same crop and time of the year. Also PET will be different at different altitude because of the different temperatures.

For the regionalization of crop water requirements it is therefore important to establish crop calendars. These calendars should have, as a minimum, contain information on planting date, date of physiological maturity and flowering date. Given these 3 dates, it is possible, with acceptable accuracy, to establish for the same crop in different areas the crop coefficients. This information can then be transformed into maps of crop coefficients.

Conclusion

Spatialization studies will allow better site-specific estimates of crop water requirements without having climatic data available for each site. They will thus help to improve water use efficiency at local level. At country level they may help to make better use of limited climatic resources by targeting irrigation projects towards areas where water demand is lower.

To achieve the full potential of this methodology the study will need to be expanded to include all Central Asian countries. To assess the inter-annual variations of the crop water requirements, time series of climatic data will need to be analyzed and surfaces prepared for individual years.

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10

Use of Treated Wastewater from Almaty (Kazakhstan) for Feed-Crop Irrigation

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Overview

At present, the problem of diversion of treated wastewater (TWW) from Almaty City in Kazakhstan is of a high importance for the relevant departments, city and province administration of the country. According to the developed projects this problem is to be mainly resolved by the way of putting into operation about 43,500 ha of irrigated lands that potentially could utilize about 2 million m^3, the estimated annual treated effluent flowing into the system.

In order to avoid overfilling of Sorbulak storage and to prevent ecological disaster it is being considered expedient to organize the use of TWW for on-farm irrigation with development of feed production and livestock production and breeding system. A research activity funded by Asian Development Bank through ICARDA (the International Center for Agriculture Research in Dry Areas) has been established to develop technologies that would be technically, economically, socially and environmentally viable. These technologies aim to utilize the available TWW to produce feed crops and to protect the human and natural resources base from potential health and environmental risk caused by disposing excess water to Ily River.

The research results showed that TWW has a low fertilizing capacity requiring the application of a designed rate of mineral fertilizers. TWW has a neutral reaction and medium mineralization. Heavy metal salt content varies within a wide concentration range. Evaluation of wastewater for the content of heavy metals was done by the parameters of maximum admissible concentrations. Wastewaters have all microelements suitable for irrigation.

When applying the whole set of agrotechnical procedures the irrigation with TWW secured an optimal development of plants and didn't cause any external changes. Over two years the yield of green mass of all crops was very high. The yield of green mass of Jerusalem artichoke (topinambur) amounted to 66.1 ton/ha of green matter in the average over two years, tubers 36.9 ton/ha, sugar sorghum 44.22 ton/ha; maize 39.47 ton/ha, sunflower 50.16 ton/ha (Figure 2). The yield of green mass of summer maize (June 15) amounted to 42.6 ton/ha, feed beet 32.73ton/ha (with thinning out higher than 50%). Selection of high yield crops for on-farm crop rotation and integrated feed production with introduction of legumes will provide a balanced ration for the animals.

Introduction

The issue of wastewater utilization in Kazakhstan has been considered at different levels. Utilization of treated wastewater (TWW) for irrigation of fodder and industrial crops as well as tree plantations was recognized as a best solution of the issue. Therefore, the projects have been developed and irrigation systems have been constructed. Thus, for utilization of Almaty City treated wastewater irrigation network covering the area of 10.5 thousand ha was constructed; water diversion was provided from Sorbulak collector. According to the project, it has been planned to develop another 33 thousand ha of irrigated lands (Figure 1).

Sorbulak collector is a natural closed depression of which the capacity is 1 km3 and the surface area is 62 km2. The collector has started receiving wastewater inflow since 1972. Fregate and Dnieper sprinkler machinery have been introduced to irrigate 10.5 ha. The irrigation system is made of reinforced-concrete pressure pipes. Irrigation scheduling has been developed under consideration of irrigation rate of 400-460 m^3/ha.

After the break up of the Soviet Union and sudden collapse of general economical status in the Country, all project and research works on the TWW utilization were interrupted. Starting from 1999, these activities have been re-initiated owing to financial and technical support provided by ICARDA, the International Center for Agriculture Research in Dry Areas.

The goal is to utilize treated wastewater from Almaty City for fodder crop and wood production and improve/protect environmental status of the region. The objective is to test conventional and non-conventional crops selecting for on-farm crop rotation those with high productivity and least heavy metal absorption capacity; to test different hybrids of fast-growing poplar trees for industrial wood production; and to explore the impact of TWW utilization on soil status, groundwater and produce's quality.

Field layout and Experimental Design

Field experiments were set up at the Serikjan farm on common light-gray low-calcareous light clay-loam non-saline soil. The soil has a low content of fertility elements. Organic matter content in the upper layers is 1.2-1.4%. The following fodder crops have been tested: topinambur, sweet and industrial sorghum, maize, barley, sunflower, Sudan grass, fodder beet, and alfalfa. Field trials have been established with double replication; the area of each was 504 m2. Agricultural techniques applied for fodder crop production were typical for the given natural-climatic zone and irrigation scheduling was developed according to the recommendations of Kazakh Research Institute of Water Management (Kazakh RIWM). Mineral fertilizers were applied with the following rates: 60 kg of nitrogen and 15 kg of phosphorus. At the phenological plots, observations on plant growth and phenology have been conducted; changes of plant external symptoms have been visually evaluated.

Results and Discussion

Over the whole vegetation period, all crops have been normally developed. Maximal height was observed for Sudan grass and topinambur: 225 and 243 cm respectively. The highest yield was obtained for topinambur (Table 1).

Biological characteristics of sorghum and Sudan grass promote fast growing of surface mass. Thus, after the first cutting on 25 July, height of Sudan grass by 30 August, i.e. after 35 days, reached to 172 cm and biomass yield was 41.25 ton/ha. The height of sorghum by this time was 81 cm, and biomass yield made 18.09 ton/ha. Spring barley for grain was damaged because of spring drought and thirsty winds. By the time of first irrigation (7 June), water deficit has been observed in barley leaves, i.e. in the morning, leaf turgor did not restore; therefore, the yield of barley made 1.36 ton/ha.

Good results have been achieved on maize of summer sowing (sowing after irrigation on 15 June). In total, there were 6 irrigation events. At the milky ripeness stage, the plant's height was 182 cm, and the biomass yield made 42.61 ton/ha.

In addition to obtaining a high yield and selecting crops for on-farm crop rotations, research activities have been focused on impact of TWW utilization on soil status and produce's quality. Wastewater from treatment plant of Almaty City and Sorbulak collector has been chemically analyzed. Wastewater coming directly from the treatment plant had better quality than the wastewater of Sorbulak collector according to its TDS, mineralization, hardness, and pH, as well as sulfate, chloride, and magnesium contents. In general, however, all parameters of macro-chemical analyses of both inflowing water and that accumulated in Sorbulak collector are well below their threshold rates. After treatment, content of 15 microelements in wastewater was below the threshold rates. In Sorbulak collector, only content of fluoride has exceeded its threshold rate. Thus, actual fluoride content was 1.02 –1.2 mg/l while the threshold rate made 1.0 mg/l. Fluoride is referred to the second class of hazardous elements. Over the whole irrigation period, microelements such as nickel, cobalt, magnesium, arsenic, molybdenum, and mercury were not observed in the wastewater. In 3 analyzed samples out of 15, a presence of cadmium (second class of hazardous elements) has been observed; its concentration was significantly below the threshold rate. The contents of cupper, zinc, lead, chrome, iron, brome, and strontium did not exceed their threshold rates. During the 1999 research activities, contents of fluoride and iron in TWW have exceeded their threshold rates. Evaluation of TWW quality according to CES standards has shown that fluoride content does not exceed its threshold rate when the fluoride concentration is above 1.5 mg/l (Table 2).

Thus, the content of macro- and microelements in Sorbulak collector water does not exceed the threshold rate; therefore, TWW is acceptable for irrigation and will not cause negative environmental impact.

With consideration of labors dealing with the TWW while operating the irrigation system and performing irrigation process it was necessary to conduct bacteriological analyses of the TWW. It has been found that bacteriological self-purification of TWW is being taken place within the transportation process from the treatment plant to Sorbulak collector. The maximum value of bacteriological contamination has been observed in summer period. According to the coli index bacteriological contamination of Sorbulak collector TWW does not exceed the threshold rate.

Pathogenic microflora (Salmonella Jondok) has been observed in the diversion canal in May and September. It has not been traced during the other months of the year. Data on content of helminthic eggs in the studied ecological system have shown that TWW of the Sorbulak collector contains in general from 6 to 66 eggs of intestinal worms in every 1100 dm3. Helminthic eggs that have no floating abilities are being quickly deposited at the bottom of the lake (according to the data of Kazakh RIWM). Consequently, soil of land irrigated by TWW from the Sorbulak collector may have potential risk of contamination by the helminthic eggs. Therefore, factors of sanitary and bacteriological hazards should be considered while developing the system of actions on labor protection and safety engineering.

Soil chemical analyses at the experimental plot have shown that in spring soil has medium content of main nutrients while by autumn, the nitrogen content is very low. Soil sampling has been conducted at 0 –40 cm depth where the active mass of the plant root system is situated. The soil status on phosphorus content looks different. Under maize, sorghum, Sudan grass, barley, and fodder beet, the phosphorus content has not varied from spring to autumn or even increased in two –four times. Hence, TWW facilitate phosphorus built up in soil sown under all grown crops except for topinambur and sunflower. One of the main features of common gray soil is that phosphorus is being well retained within the whole soil profile.

To evaluate the impact of TWW microelements on the soil status soil sampling has been carried out at the experimental plot in spring and autumn after irrigation. The analyses have not shown any particular difference between summer and autumn content of microelements. Insignificant transport of microelements within the soil horizons has been caused by irrigation water effect on the soil profile and soil variegation. Ground contamination has been evaluated on virgin soils. The content of microelements in virgin soils was in most of the cases equal to that in the soil of experimental plot. Microelements content in soils of both experimental plot and undeveloped land was below the threshold rate and did not increase from 1999 to 2000.

Produced fodder crop quality was evaluated by 8 microelements such as Zn, Fe, Cd, Cu, Cr, Ni, Pb, and Co. The analyses have shown that the microelement contents in produced crops do not exceed maximal admissible levels and threshold rates. Thus, TWW utilization for fodder crop production contributes to high yield productivity and considerably improves environmental status of Ily intermountain depression.

Summary

Good result have been achieved utilizing what is being consider at one point as a "waste" which in fact is a "source" of irrigation water that not only brings economic benefits, but also environment protection to the valuable natural resources of the region. The preliminary results indicated that large quantity of forage that contain heavy metal concentration below the toxicity level and other industrial crops could be produced with less amount of commercial fertilizer capitalizing on the nutritional value of the TWW to crop production. This source of water, which can be used as supplemental irrigation by annually applying not more than 500 m3 per ha may produce significant amount of forage or silage to supply the livestock industry in the country and bring economical and social benefit to the region and in turn to the country. This research activity at this site will be continued with comprehensive monitoring studies to address the following issues:

- Testing of traditional and non-traditional crops;
- Introduction of feed crop rotations and wood plantations;
- Rational irrigation schedules, irrigation practices, and watering of rangelands;
- Well balanced ration for animals;
- Production of fish flower from the lake body;
- Social and economic efficiency of the system of utilizing marginal water for agriculture production and environment protection;
- Continue soil, water, and groundwater monitoring for residual chemical and biological hazard; and
- Testing the effect of the agriculture product quality on the quality of the final produce (i.e. meat and milk).

Acknowledgments

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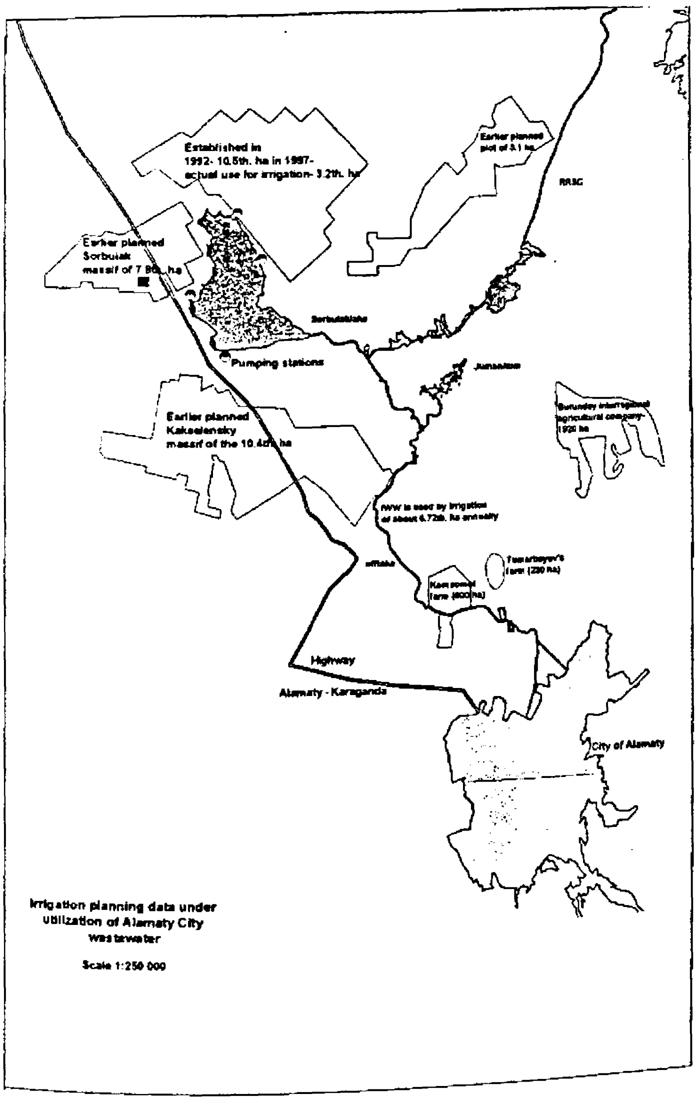

Figure 1. Layout of the Treated Wastewater Project and the location of the research site.

Figure 2. Measuring the height of sunflower at its blossoming stage

Table 1. Fodder crop yield under irrigation by TWW from the Sorbulak collector.

Crop	Produce	Yield, ton/ha		Average yield, ton/ha
		1999	2000	
Topinambur	Biomass	54.16	78.0	66.05
	Tubers	30.50	43.30	36.60
	Total	84.66	121.30	102.65
Sunflower	Biomass	50.38	49.95	50.16
Sweet sorghum	Biomass	40.54	47.91	44.22
Industrial sorghum	Biomass	41.69	-	-
Maize	Biomass	33.53	45.43	39.47
Sudan grass	Biomass	-	62.50	-
Barley	Grains	-	1.36	-
Fodder beet	Tubers	-	32.73	-

Note: biomass yield is for one hay cutting conducted at the milky-waxy stage of ripeness

Table 2 (Part a). Microelements content in TWW of the Sorbulak collector (2000).

Sampling point and date	Cu	Zn	Ni	Pb	Cd	Co	Mn	F
Water divider:								
6 June	0.004	0.026	Nil	0.0013	Nil	Nil	Nil	0.92
16 June	0.002	0.04	-"-	0.001	-"-	-"-	-"-	0.97
25 June	0.01	0.06	-"-	Nil	-"-	-"-	-"-	0.93
4 July	Nil	0.002	-"-	0.005	-"-	-"-	-"-	0.82
27 July	0.002	0.027	-"-	Nil	-"-	-"-	-"-	0.93
8 August	0.057	0.026	-"-	Nil	-"-	-"-	-"-	0.86
Sorbulak collector:								
6 June	0.002	0.019	Nil	0.00017	Nil	Nil	Nil	1.15
16 June	0.05	0.07	-"-	0.007	-"-	-"-	-"-	1.20
25 June	0.05	0.08	-"-	Nil	-"-	-"-	-"-	1.16
4 July	0.0016	0.0024	-"-	0.016	-"-	-"-	-"-	1.11
27 July	0.0051	Nil	-"-	0.07	-"-	-"-	-"-	1.15
8 August	0.042	0.015	-"-	Nil	-"-	-"-	-"-	1.02
Pump station:								
6 June	0.005	0.014	Nil	0.001	Nil	Nil	Nil	1.14
16 June	0.005	0.015	-"-	0.001	-"-	-"-	-"-	1.18
25 June	0.04	0.07	-"-	Nil	-"-	-"-	-"-	1.07
04 July	0.004	0.012	-"-	0.074	0.0004	-"-	-"-	1.19
27 July	0.0017	0.008	-"-	Nil	0.003	-"-	-"-	1.42
8 August	0.07	0.11	-"-	0.065	-"-	-"-	-"-	1.0
Threshold rates								
USSR	0.2	2.0	0.5	0.2	0.03	0.05	0.2	1.0
FAO	0.2	2.0	0.2	5.0	0.01	0.05	0.2	1.0
CES*	0.5	10.0	0.5	0.2	0.001	0.5	0.2-0.8	1.5 - 10.0

* Council for Economic Support

Table 2 (Part b). Microelements content in TWW of the Sorbulak collector (2000).

Sampling point and date	Cr	As	Fe	Br	Mo	Hg	Sr
Water divider:							
6 June	0.006	Nil	0.17	Nil	Nil	Nil	0.35
16 June	0.006	-"-	0.22	0.01	-"-	-"-	0.20
25 June	0.012	-"-	0.23	Nil	-"-	-"-	0.12
4 July	Nil	-"-	0.17	0.03	-"-	-"-	0.22
27 July	Nil	-"-	0.32	0.05	-"-	-"-	0.29
8 August	Nil	-"-	0.30	0.03			0.39
Sorbulak collector:							
6 June	0.0065	Nil	0.06	0.13	-"-	-"-	0.43
16 June	0.006	-"-	0.21	0.19	-"-	-"-	0.45
25 June	0.034	-"-	0.18	0.20	-"-	-"-	0.42
4 July	Nil	-"-	0.12	0.17	-"-	-"-	0.34
27 July	Nil	-"-	0.38	0.24	-"-	-"-	0.44
8 August	Nil	-"-	0.15	Nil	-"-	-"-	0.70
Pump station:							
6 June	0.0042	Nil	0.09	0.15	-"-	-"-	0.35
16 June	0.005	-"-	0.19	0.21	-"-	-"-	0.40
25 June	0.012	-"-	0.07	0.18	-"-	-"-	0.37
04 July	Nil	-"-	0.12	0.17	-"-	-"-	0.46
27 July	Nil	-"-	0.30	0.26	-"-	-"-	0.50
8 August	Nil	-"-	0.22	0.34	-"-	-"-	0.70
Threshold rates							
USSR	0.1	0.1	5.0			0.005	
FAO	0.1	0.1	5.0			-	
CES*	0.5	0.1	1.5-10			0.005	

* Council for Economic Support

11

Irrigated Agriculture And Sustainable Water Management Strategies in the Tarim Basin

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Overview

There is a long history of irrigation agriculture in the Tarim Basin. In recent 50 years, the irrigation areas increased rapidly. At the same time the desertification areas also increased. The area of natural vegetation and the ecotone between farmland and desert is decreased. Because most of the river water is carried to irrigation canal for agriculture, several serious ecological problems are created in the lower reaches. The irrigated agriculture with high water consumption and low economic benefit faces challenge. The paper introduces the water resources and irrigated agriculture situation in the Tarim Basin and mentions some problems and methods for developing sustainable agriculture. The bases for developing sustainable agriculture in the Tarim Basin are: first, the united water management in the whole river system must be formed; second, water-saving irrigation method should be used; third, ecological water muse be remained.

Introduction

The Tarim Basin is the biggest arid inland basin in China. It is located in Asia European Continent and far away from the sea. The total area is 1.02 million square kilometer. Mountain area is 0.587 million square kilometer and desert area is 0.333 million square kilometer. The Tarim Basin is one of the driest land in the world. There are 2.081 million hectare of irrigation area, 8.257 million of population, and 43.634 billion cubic meter water resources (6.074 billion cubic meter water resources is from neighbor countries). In the farmland plain the annual precipitation is 30-80 mm, the dry index is more than 10, and the solar radiation is 5.8 billion J/m^2 per year.

The Tarim Basin is the ideal land for agriculture. The heat conditions are favorable and waste land are wide distributed. Water resources supplied by snow and glaciers in the mountain areas are stabilization. Now this region is the biggest cotton production region in China and 3.7% of the world cotton is produced in the region. There are oil and gas resources in the region.

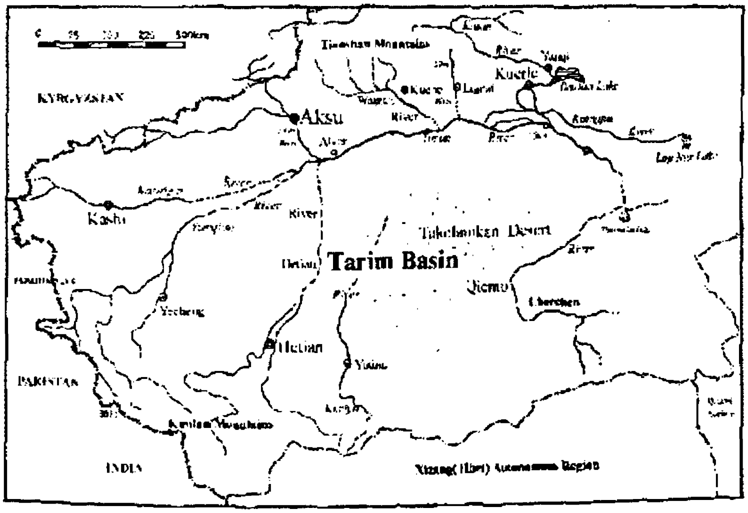

Figure 1. The map of the Tarim river basin system

The Basic Conditions in the Tarim Basin

There are 39.2×10^9 m^3 of river water and 4.455×10^9 m^3 of underground water in the Tarim Basin. Most of the water comes from the 144 rivers originated in the south slopes of the Tianshan Mountains, the north slopes of the Kunlun mountains, and the Pamir highlands. The mountain region is water supply region, the plains comprise the water consumption region.

The River Systems and Water Resources

Most of the rivers in the Tarim Basin are small rivers and their discharges are less than 0.1×10^9 m^3, begin in glaciers and stop in the desert. There are 9 rivers that annual runoff is more than 1×10^9 m^3. According to the regional zone and river channel relationship, seven rivers system are divided. The Tarim river system consist of three tributaries (the Aksu River, the Yarkant River and the Hotan River), the Kashigar River consist of small rivers begin in Pamir highlands, the Weigan River, the Dina River and the Kaidu-Kongque River come from the Tianshan Mountains, the Keriya River and the Qarqan River come from the Kunlun Mountains. The water resources of these 7 rivers are listed in Table 1.

Other water resources can be used in agriculture including 0.028×10^9 m^3 river runoff from small streams in the east desert region, and 16.9325×10^9 m^3 ground water transformed by surface water in the plain region.

Table 1. Water Resources in Tarim River Basin (unit: 10^9 m^3)

River name	Tarim	Kashigar	Kaidu	Weigan	Dina	keriya	Qarqan
Surface Runoff	22.048	5.086	3.97	3.46	6.17	2.11	1.86
Ground water resources	1.7991	0.7425	0.605	0.7648	0.1537	0.2646	0.1403
Total water resources	23.8471	5.8285	4.575	4.2248	6.3237	2.3746	2.0003

Transboundary Water Fluxes with Neighboring Countries

There are 3 tributaries that originate outside China. The upper reaches of the Aksu River – the Tuoshigan River and the Kunmalike River begin in Kirghizstan. The tributary of the Kashigar River – the Kezhir River begins in Kirghizstan and Tadzhikistan. The tributary of Yarkant River - Keleqing River begins in Pakistan. All of the tributaries have not the hydrometric station and lack of data. The total of water quantity come from above 3 countries are 6.303×109 m^3 (estimated according to the basin areas and runoff contour map).

Key Characteristics of Water Resources

- *The distribution of the water resources is more in the west than in the east, and more in the north than in the south.* Total of 83.5% of water resources is in the west part along the line of 83°E, and 56.8% is in the north part along the line of 39°N. There are many high mountains and glaciers and snow cover, precipitation in the west part is more than in the east part. In the east part of the Tarim Basin there is no high mountains and rainfall is quite limited.
- *Water supply is stable. The monthly variations of discharge are large, whereas the yearly variations of discharge are small.* The river discharge dispersion coefficient for most of the river in the Tarim Basin is less than 0.2. The distribution of discharge every year is very different. The discharge of

large 4 mouths takes up 70-80% of the total annual discharge. In the Yulongkax River, the discharge of large 4 months takes up 89.2% of the total annual discharge.

- *The main supply of runoff is glacier melt water.* Water resources in the Tarim Basin Rivers have 40.2% of glacier water. The highest glacier-melt water is in the Muzhati river, for which glacier melt water takes up 81.8% of the total runoff.
- *The mountain region is the runoff formation region, the plain region is the water consumption region.* The precipitation is higher, the evaporation is lesser in the mountain region than in the plain region. Mountain region is the wet island in arid land. In the Tarim Basin the runoff formation areas is larger than plain area. This is the main reason why in plain area there is only little precipitation but a great quantity of water. This condition is different from other arid lands in the world.
- *Most of the underground water is transformed by surface water.* In plain region, there are 79.2% of total underground water is transformed by surface water.
- *The quality of runoff and underground water is become worse along flow route.* The water quality of runoff in the upper reaches is better than that in the lower reaches. Usually the water quality becomes worse after rivers enter plain region. The salt content of the underground water in alluvial fan is usually less than 0.5g/l. But in the desert areas it is more than 4.0g/l.

Economic Conditions

There are five administration districts including 41 counties and 56 state farms in the Tarim Basin. In 1998, the population was 8.257 million and the cultivated area was 1.103 million ha. The annual gross domestic product is 30.63 billion Chinese Yuan (3.69 billion US dollar). The total food yield is 0.3675 million ton and cotton yield is 0.685 million tons. The Tarim Basin is the biggest cotton production region in China; 17.1% of the Chinese cotton and 3.7% of the world cotton are produced in the region. The Tarim Basin also has gas and oil resources. The region is the potential important oil supply place in China.

The situation and problems for irrigated agriculture

No agriculture can survive in the Tarim Basin without irrigation. The lands between the mountains and desert is the mainly agriculture farmland. There are 5.8 million ha of suitable waste land available for agriculture.

Irrigation Engineering Conditions

Up to 1998, there are 167 reservoirs. The total volume of storage in the reservoirs is 3.82×10^9 m^3. There are 382 sluice are constructed for carrying water. The total length of irrigation canal is 0.1574 million kilometers and the lined canal length is 35.4 thousands kilometers.

Table 2. The irrigated agriculture situation in Tarim River in 1995

Item	unit	Aksu river	Yarkant river	Hotan river	Total
Total water resources	10^9 m^3	8.138	7.435	4.458	20.031
Including: river runoff	10^9 m^3	7.849	7.354	4.350	19.553
Total water consumption	10^9 m^3	5.65	6.79	2.522	14.962
Including:irrigation water	10^9 m^3	5.512	6.081	2.506	14.099
River water consumption	10^9 m^3	5.512	6.067	2.506	14.085
Ground water consumption	10^9 m^3	0	0.014	0	0.014
River water utilized rate	%	59.39	87.3	70.06	69.43
Irrigation areas	1000 ha	317.31	393.61	134.6	845.52
Cotton areas	1000 ha	122.6	166.05	26.6	315.25
Number of Reservoirs	site	6	39	22	67
Reservoir volume	10^9 m^3	4.97	12.37	5.62	22.95
Runoff regulated coefficient		0.063	0.168	0.129	0.12
Canal system density	km/kha	89.6	142.2	171.5	134.4
Canal utilization coefficient		0.396	0.415	0.43	0.414
Canal lined rate	%	10.81	8.16	20.83	13.27
Gross irrigating quota	m^3/ha	17371	15414	18618	16658
Agriculture total output	t	809698	1007981	457806	2275485
Including: cotton output	t	188101	225615	25980	439696
Total agriculture output value	Million Chinese Yuan	776.3415	39.493356	1675.4197	6401.097
Per m^3 water yield	kg/m^3	0.147	0.166	0.183	0.162
For cotton	kg/m^3	0.088	0.088	0.052	0.084
For food	kg/m^3	0.31	0.21	0.17	0.23
Per m^3 water value	Yuan/m^3	0.14	0.65	0.67	0.45

*not including the water from abroad

The total length of drainage canal is 70.7 thousands km. There are 191 irrigation regions that the farmland is more than 700 ha. The effective irrigation area is 0.13389 million ha. There are 17 irrigation regions that the farmland is more than 20 thousands ha. The effective irrigation area is 0.576 million ha.

Irrigation Water Conditions

There are 95% of the total utilized waters is for irrigation. for most of the small river, 70%-80% of the river water are carried for irrigation. In 1998 the total water consumption is 26.46 ×109 m^3. Agriculture irrigation consumption is 26.29 ×109 m^3 (99.36%). Irrigation quota is 11910-19779 m^3/ha. The canal effective utilization coefficient is 0.42-0.74.

After 1990, the river water utilized for agriculture irrigation increased slowly. The underground water utilized for agriculture irrigation increase quickly. Now water utilization for irrigated agriculture is changing from just using river water to both using river water and groundwater. Table 2 shows the irrigated agriculture situation for the main water system of the Tarim Basin – for the three source branches of the Tarim River.

Irrigation Area Development Conditions

It is the quick expenditure period for irrigation area in the Tarim Basin in recent 50 years. The average annual increased irrigation area is 22.079 thousands ha. Figure 2 is the irrigation areas changing map in the Tarim Basin.

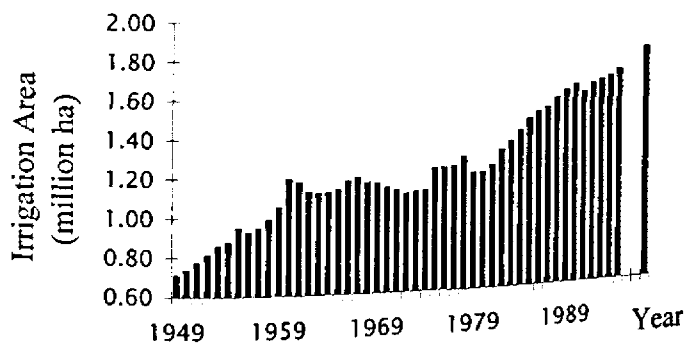

Figure 2 Irrigation area in Tarim River Basin

Challenges Faced in Irrigated Agriculture

- *The percentage of river water carried to irrigation area is high and the irrigation water utilization efficiency is low.* Through the water carry system, 70-80% of the river water is carried to irrigation areas. A lot of water is lost on the way. The average canal water utilization coefficient is about 0.4. In the Tarim Basin there are many plain reservoirs in the farmland district. The reservoir water utilization efficiency is only 50%. The seepage and evaporation loss is about 50%. It means that more than 50% of the river water is lost before it enters the farmland.
- *Traditional surface irrigation method is the main irrigation method in the Tarim Basin.* The water loss in farmland is high. It is suggested that ditch irrigation should be used. The plastic slice irrigation is the widespread method in cotton farmland. Sometimes flooding irrigation is used when the water is abundant. Traditional surface irrigation has caused farmland water deep infiltration and the underground water table risen after irrigation.
- *The contradiction of water supply and water requirement during spring season. There is a lack of irrigation reservoirs.* Because the temperature in mountain regions rises slower than in agriculture regions. The irrigation water consumption graph and discharge hydrograph is not coincidental. The reservoir could not provide enough water for irrigation. The contradiction of water supply and water requirement is serious during spring season. During March to May, 30%--40% of the total irrigating water is consumed, and only 10%--20% of the annual discharge is formed in these 3 months.
- *Low irrigation water benefit.* In the Tarim Basin one cubic meter water yield 0.23 kg food, or 0.084 kg cotton, the agriculture value is 0.45 Chinese Yuan. Compared with other advanced irrigation area in Xinjiang it is lower. The agriculture development in Tarim Basin is based on enlargement the irrigation areas and increased the water utilization.
- *The primordial and secondary salinization and alkalization in irrigated farmland are widespread.* The salt content is high in the shallow soil of Tarim Basin. It is essential that

using high irrigation quota to reclaim farmland. Since the lack of drainage system, several years late the underground water table is rise. The salt move to upper layer again. Now 1/3 -1/4 of the farmland have salinity problem.

- *The contradiction of agriculture and ecological water requirement.* The natural plants based on flood and underground water supply are dead. The natural plant areas are reduced and ecological environment is affected adversely. During the recent 50 years, the irrigation water consumption increased and the river water decreased continuously.
- *The water quality in the lower reach is worse.* Now the drainage waters from the irrigation areas usually flow to lower reach of the river. The river has become the main drainage canal. The saline waters enter the river and the water quality gets worse. In 1958, the annual average water salt content was 0.73 g/l in the main stream of Tarim River; it was less than 1 g/l all the time. In 1976, there were 6 months when the salt content more than 1g/l. In 1984, there were 9 months the salt content was more than 1g/l. In 1991, all the time the salt content was more than 1g/l. During the recent 3 years, in middle reach and lower reach of the Tarim River, the water salt content in the plain reservoir has been more than 2g/l all the time. Apart from the flooding season the salt content is 3.0 - 6.0 g/l for the river water. Recent 10 years the raise speed of the water salt content in Tarim river is 5% per year.
- *Water price is lower and water management policy should be improved.* Firstly now there is not a unity water management agency in Tarim Basin. Different rivers belong to different water management agency authorized by local government. Secondly for most of the irrigation regions the water bill is based on farmland areas. Thirdly the price of river water and groundwater is different. The groundwater price is 5-10 times high compared with river water. The price of river water is about 0.4 – 0.9 U.S. dollar/ 100 m^3. High underground water price is the reason why the underground water utilization rate is lower.

Sustainable water management Strategies

For developing irrigation agriculture most of the river water are consumed. Two very important ecological problems are caused: (1) Secondary soil salinization and alkaline problem in irrigation region. (2) The desertification and natural vegetation decrease outside the irrigation regions. It has become the main problem that achieving the sustainable irrigated agriculture development and water utilization, satisfying the water requirement for social, economic and ecological needs. The urgent problem is unification and integration of water management. Focused on the water resources and water utilization situation, some suggestions are listed below.

- *Establish a unity water management organization for managing all rivers and water resources.* In 1990 the Tarim Basin Management Bureau was established. But the management function is limited in the main stream of Tarim River. Now the task of TRBMB is: (1) Ensure the river water arrives in the lower reach, protected and renewed the nature desert plant in the lower reach land. (2) Establish a general program and water utilization plan for the main stream of Tarim River. The river program and water utilization plan of the whole river is lacking. Now every branch river or small river system has the water management bureau authorized different local government. It is urgently needed to change this administration relationship. The TRBMB is the highest water administration organization in Tarim Basin. Other river water management departments are authorized by TRBMB.
- *Promulgate a water policy law.* Based on the water policy law to administrate the Tarim Basin river water. Some regulation and law for the river water management are established. Including "The water policy and temporary regulation for water resources management in the Tarim Basin " and "Tarim Basin management methods". "The water resources administration law in Tarim river Basin" is agreed by Xinjiang People's congress.
- *Established a uniform water price system.* Using the price method to control water consumption. Now the water price in the Tarim Basin is lower. It is urgently to reform the

water price. Firstly, according to the water measuring result to pay the water bill. Secondly, the water price is raised to the costs of water supply. Thirdly, adopting different water utilization price policy and encouraging saving water. If one water user exceeded his normal permission water quantity the price is different. Fourthly, unifying and harmonizing the surface water and underground water price. Encourage pumping and using the underground water.

- *Construct more infrastructure for water engineering and improving the existed infrastructure.* Increased the investment. Constructed the mountain areas reservoir engineering, it is benefit to resolve the contradiction of water supply and requirement. It can also control all water resources. For irrigated agriculture developing and ecological improving it is fine too. It is suggest that Tarim River is one national big river should be invested by national budget.
- *Develop Water-saving Agriculture.* Using water-saving irrigation methods and changing the crop structure are the key problems. For crop structure regulation, it should be done that developing a compound structure of agriculture, forestry and animal husbandry, and Increasing the grass and tree areas and growing the water-saving crops. This is the base for ecological agriculture. For irrigation methods, it should be done that extending the sprinkler and drip irrigation and tube water carry technology, and Constructing the lined irrigation canal and disallowing the flood irrigation method.

Conclusions

In Tarim Basin there is a long history of developing irrigated agriculture. Since the 1950s-60s, a large scale agriculture exploitation began in the Tarim Basin. Along with the irrigation areas and water consumption increase some ecological problems, nature vegetation areas decrease and desertification areas increase, are appeared.

Now irrigated agriculture has the decreased benefit and high water consumption problems. The sustainable agriculture development faces numerous challenges.

Changing the traditional high water consumption agriculture pattern, fulfilling the union water management policy and insuring the ecological water requirements are the key issues for developing sustainable agriculture in Tarim Basin.

12

Integrating Land Management in Dry Areas

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Land Degradation as a Global Problem

Land degradation is defined as a process that leads to reduction the productivity of land for useful purposes and is typically a result of soil erosion, wind erosion, water erosion, soil salinization, waterlogging, chemical deterioration, or a combination of these factors. Land degradation is a global problem where marginal lands are turned into wastelands and natural ecosystems are destroyed. The immediate causes include deforestation, poor management of water resources, inappropriate land use practices, overuse of chemicals, fertilizers and pesticides, and disposal of domestic and industrial wastes. The underlying driving forces include rapidly increasing population, economic policies that over-exploit natural resources, and rapid and often poorly managed industrial and urban development. The impacts of land degradation are severe on both the human society and ecosystems.

The UN estimates that some 70 per cent of the 5.2 billion hectares of drylands used for agriculture around the world are already degraded (UNEP, 2000). This impacts approximately 250 million people across the world – some estimates cite number of people at risk as being four times higher than this. As an example, the worldwide area of arable land per person has reduced by as much as 25% during the last quarter of the twentieth century. This has serious implications for food security and livelihood of people dependent on degraded lands. The impact of land degradation on ecosystems is apparent in destruction of biodiversity resources. According to UNEP estimates, about 65 million hectares of forest were lost globally during just five years between 1990 and 1995 (UNEP, 2000). The resultant loss in biodiversity at genetic, species and community level is also severe. These projections demand the attention of the international community and a coordinated effort to overcome these challenges.

Integrated Land Management Approaches

The most vulnerable areas in any ecosystem are the ones at its periphery. Most of the land erosion, degradation of soil quality, loss of biodiversity, and eventual loss of productivity occurs in these marginal – but high-priority – lands. This is particularly true for "Dry Areas", those comprising arid, semi-arid and dry sub-humid regions. Sustainable management strategies in these dry areas are needed for protection, preservation and reclamation or rehabilitation in these fragile systems and natural resources contained therein. Such strategies are closely linked to human development and quality of life in these marginal areas.

Development of integrated approaches is critical to minimizing land degradation and the related societal and economic impacts. There is a need to promote actions for building and strengthening existing institutional capacities for regional, national and basin-level agencies to effectively address and integrate cross-sectoral aspects. However, defining such integrated approaches is a complex job and the outcome would vary from region to region. In order to develop a general framework for such integrated approaches, there four key dimensions of the problem, as shown in Figure 1, that must be considered.

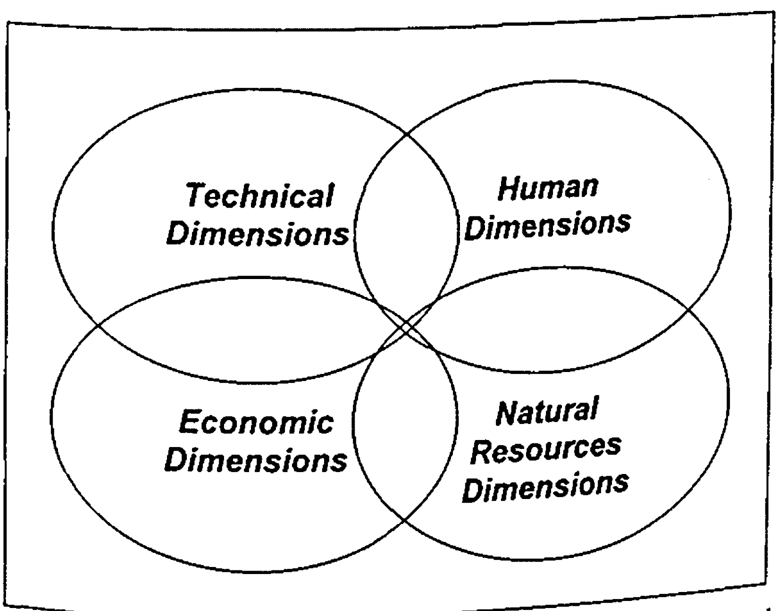

Figure 1. Key dimensions of the integrated approaches to land management.

A. Technical Dimensions:

- All renewable natural resources (water, soil, vegetation, etc.) should be taken into account when developing integrated management programs;
- Innovative solutions have to be identified for managing land degradation, mainly through water use efficiency and productivity, and soil conservation;
- Potential conflicts and synergies between highlands and lowlands should be given due consideration, particularly because highlands and mountains serve as water towers for the lowlands; and
- Due consideration be given to trans-ecozone characteristics of resources – especially water. Planning and conflict resolution on a trans-ecozone level become crucial in approaches to improve the resources situation in dry areas.

B. Human Dimensions:

- Localized approaches for land ownership and land tenure are often critical in conservation of resources;
- Impacts on livelihood of local people need to be accounted for when designing and discussing resource management approaches; alternative livelihoods for communities that may be impacted have to be developed;
- Effects of indigenous practices on natural resources, both positive and negative, should be accounted for;
- Whenever applicable, indirect social benefits of integrated management should be explicitly considered; and
- Mechanisms for conflict resolution during the implementation of management approaches should be built into the programmes.

C. Economic Dimensions:

- Evaluation of social, environmental and economic costs and benefits has to be undertaken to ensure long-term sustainability or viability of integrated approaches;
- Capital investment into developing new infrastructure as well as maintaining existing and traditional practices should be made; and
- Linkages to national economic development should be elaborated.

D. Natural Resource Dimensions:

- Rehabilitation of ecosystems in marginal lands should have the highest priority in integrated programmes; and
- Whenever applicable, in situ conservation of biodiversity within ecosystems should be considered.

These dimensions are closely interlinked with each other and need to be considered explicitly to develop fully integrated approaches. A number of international organizations are already working towards development of such approaches; although successful examples of such programmes are few.

Development of a UNU Project on the Subject

In consideration of the multi-dimensional challenges, UNU has undertaken the development of a project framework. With the view that this project is focused on developing countries in dry areas – particularly the region comprising Northern Africa, Central Asia, Middle East and China – the following objectives are identified:

- To facilitate development of integrated management approaches for sustainable utilization of natural resources, including land, water and biodiversity resources in marginal lands;
- Identify key research areas in land and natural resource management that can benefit the most from capacity building;
- Develop appropriate capacity building programmes, with emphasis on south-south collaboration for transfer of environmentally-sound technologies; and
- Catalyze development of networks of researchers and institutions working in various disciplines and geographical settings.

Project Framework

The project will be implemented through a network of researchers and institutions. It will comprise various sub-projects implemented through the partners within the network. Institutional collaborations with other international organizations working on similar issues will also be sought.

Project Priority Areas

The project seeks to develop integration across disciplines and vertically between governance and land management. To achieve integration at these various levels, a subset of priority areas have been identified:

- Assessing threats to marginal lands, which can be achieved through quantifying threats to water, land and biodiversity resources;
- Development of assessment maps to identify areas under high level of stress and threats to natural resources;
- Evaluation of land productivity, considering temporal changes in land use and land cover, and identifying their causes;
- Comparative evaluation of land management approaches in the region, with the objective of sharing results and transfer of environmentally-sound technologies;
- Identification of correlation with other regimes such as climate change and biodiversity conservation, for example, through evaluating carbon sequestration capacity as a result of integrated land management.

Project Elements

A project within the network must contain four elements to ensure that the results and benefits of the project are fully transferred to the communities or target audience. These elements are in accordance with UNU's objectives and utilize its existing institutional strengths.

- *Network Development*: This can be achieved through meetings and workshops followed up by publications and Internet communication. The main purposes are to enhance information exchange and identify the specific research needs of marginal lands in terms of capacity building.
- *Development of Training Programmes*: Based on the needs identified during network development, training programmes with well-defined objectives and target audience should be developed. These training programmes may also include development of training materials such as textbooks, workbooks, manuals, CD-ROMs.

- *Research on Integrated Land Management in Marginal Lands*: This targeted research work should emphasize the importance of integrated management of water and land resources and identify methodologies/techniques that are environmentally-sound.
- *Dissemination of Environmentally-Sound Information*: Because UNU focuses on a south-south collaboration, an important part is to share the project results as well as information on technologies that have been successfully applied in the developing countries.

Quality Criteria

For projects to affiliate with the UNU project, some basic criteria must be met. These criteria can be considered as quality criteria for the projects and should include the following:

- The project must provide integration of disciplines and approaches;
- The group undertaking the work must be multidisciplinary in its composition, involvement of NGOs and experts in traditional technologies should be considered;
- The scientists in the group must be recognized in their respective field for quality of their research work;
- There should be clear prospects of continuity and sustainability of the project itself;
- The research work must include explicit mechanisms for transferring the knowledge and expertise to local communities and target groups.

On the whole, the project implementation and selection of sub-projects is overseen by a Steering Committee. The network within the project is maintained and expanded through a series of workshops, held annually. These workshops focus on various dimensions of a selected subject area and geographical region (please see the UNU Desertification Series: UNU, 1998; and UNU, 1999). Dissemination activities will include publication of workshop proceedings and preparation of other project materials.

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13

Opportunities for Research on Floodwater Spreading – Future Challenges

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Overview

Breaking the vicious circle of poverty, famine, need for grazing and cropland, and environmental degradation factors that lead to desertification, is inevitable if the humankind is to continue to exist on the planet earth. Although overpopulation is one of the major causes of the processes leading to desertification, as we cannot reverse the exponential growth rate easily, we have to develop a strategy which may make at least a dent in the circle.

Water shortage is pushing large masses to the brink. This is true for both the xeric and mesic environments. Not only the developing countries feel the pressure, but also the advanced nations as well, of course in different contexts. While water, no matter how impure, is a heaven sent gift for some desert inhabitants, an abundance of polluted water is menacing the industrialized countries. Flooding wreaks havoc on all nations. No country is immune to this nature's whim. Drought is another ever-present threat to the very existence of people who have to produce their food on land.

Prudent water management is the key to many aspects of desertification control. As floodwater and "wastelands" are the two most precious but overlooked resources in the deserts, the logical utilization of these blessings in disguise is a means of providing a more fruitful life for some desert dwellers.

Placing all of these issues into one frame and contemplating their inter-relationships brings out a unique solution to many of these problems: Floodwater spreading as a sustainable practice. The status of our knowledge, as far as the resources which have been at the author's disposal could convey, has been presented in this paper; myriad of unanswered questions still remain, however. Consider the following:

1. Irrigation with floodwater is the oldest method of watering field crops, perhaps learned from the nature. The author is not aware of any methodological research in this field.
2. The qanat technology has been around for a few millennia and it has been disseminated from Iran to many parts of the world. Hydraulics of qanat, particularly in relation to its artificial

recharge, is relatively unknown. Why is it so? I advance some thoughts; certainly there are others.

Centralization of advanced research in Europe and the USA. Needless to say, what makes a name for a researcher is dazzling the scientific community with the discoveries. Floodwater spreading is an old hat! These are three examples in irrigation optimization:

a. As about 99% of the water consumed by vegetation is transpired, a small reduction in the transpiration rate could amount to a considerable saving in water. The bright idea of application of biochemicals to the leaf surface to partially close the stomata (Zelitch, 1969) and its limitations (Gale et al., 1967) have not died completely (Kramer, 1983, p.412-414).
b. As carbon is the building block of the organic material and CO2 is used in the photosynthetic processes, increasing CO2 concentration in the plant environment is under careful consideration (Tinus, 1974; King and Greer, 1986; Allen, Jr., 1990; Chaudhuri et al., 1990). Applicability of this idea is an open question.
c. As sea- water is practically limitless a few investigators have claimed success using the highly saline water for irrigation of certain crops (Boyko, 1968; Epstein and Norlyn, 1977). Apparently, others have not been able to verify their findings!

The mean annual precipitation of North America (including Central America but excluding the Canadian Archipelago) is 670-mm, of which 287-mm (2000 billion m^3) runs off to the oceans; somewhat similar situation is prevalent in Europe. Therefore, it is logical that European and American scientists should not be concerned about water shortage as much as the people of the arid and semi-arid lands should. Another reason is the mentality of most of these scientists and their sponsors who look for spectacular and expensive projects, quite the opposite of what is needed by the developing nations.

With this background, it is encouraging to know that the US Congress (OTA, 1983) seriously considers the use of water harvesting techniques. This may lead to some basic research that could eliminate some of the obstacles.

It is of vital importance to realize that the era of cheap water is over. Therefore, tremendous intellectual and financial resources should be directed towards solving the water crisis. As many people consider flood a curse it is logical to harness it and posses its water! There are three distinct areas in floodwater spreading (FWS) research needs: Technological, biological and sociological, which are discussed briefly below:

Technological Research Needs

1. Hydraulics of FWS consisting of diversion weirs, aprons, sand excluders, turnouts, inundation canals (ICs), conveyance-spreader channels (CSCs), level-silled channels (LSCs) and gaps. It is important to realize that flood is an unsteady, nonuniform flow and its spreading undoubtedly follows the same conditions;
2. Hydraulics of irrigation with floodwater (IF);
3. Hydraulics of sediment transport in the FWS systems;
4. Design optimization in ICs, CSCs and LSCs for sedimentation reduction in them, and a uniform FWS from the CSC overflowing sill;
5. Design optimization for LSCs with regard to their location in the FWS systems;
6. Spacing optimization for the LSCs with regard to their function (IF, sedimentation basins, SBs);
7. Design optimization for the recharge ponds (RPs) and SBs with regard to their geometric shapes and local conditions;
8. Fixation of the moving sand by the fine-grained sediment (warping) and strip cropping in the FWS systems;
9. Construction of diversion weirs, turnouts and wasteways with regard to the materials and methods;
10. Construction of sand excluders;
11. Desiltation of the IC and the channels, and utilization of the sediment for leveling and reclamation of eroded land and brick manufacturing;
12. Groundwater hydrology and hydraulics in the artificial recharge of groundwater (ARG) systems and mapping the phreatic surface for utilization optimization;
13. Contingency groundwater reserves for drought periods and prevention of salt- water intrusion into freshwater aquifers;

14. Characterization of clay species in the contributing watersheds, their translocation into aquifers and their probable transformation into other minerals in the ARG systems;
15. Design and construction of the ARG and FWS systems with regard to the development of clean cities (Desert Utopias).

Biological Research Needs

Irrigation with floodwater (IF) or runoff farming (ROF) is an intermediate stage between the irrigated and dryland farming. If floods occur at the opportune time and at the right rate the watered crops behave as they would in irrigated agriculture. On the other extreme, the crops respond to a floodless season as in the rainfed systems. In an average year, however, they receive less water than in the former and more water than in the latter. Therefore, application of the results obtained in both types of agriculture to runoff farming is a mistake and implementation of comparative studies is inevitable if dependable results are expected.

Acceptance of the rooting - zone as the water reservoir is the starting point in the ROF; therefore, characterization of the physical, chemical and biological properties of the soil on which crops are grown is essential. Selection and/or breeding of the species and varieties adapted to the ROF are another point to consider.

It is extremely important to realize that root distribution in the soil is dependent on the interaction of the genetic characteristics of the plant with the physical, chemical and microbiological properties of the soil and the microclimate in the plant canopy. It is only under favorable environmental conditions that a plant expresses its full potential in growth and reproduction (Brown and Scott, 1984). Therefore, the plant and its growth medium have to be studied as an integral system.

As water is the most limiting factor in arid and semi-arid agriculture, and just one watering at the right time dictates the difference between success and failure, it is logical to start with the adaptation trials of the available stock in the FWS systems.

Breeding plant varieties, particularly cereal crops, for use in the FWS systems is the next step in optimization of IF. As reliable results are obtained only if the cultivars and lines are selected under irrigation with floodwater, therefore, the routine breeding process, in which plants are watered regularly, is not applicable to this activity. Hurd (1976) believed that as a plant yield is related to its response to the environment, therefore, its water use efficiency and the products of its photosynthetic processes are specifically related to that environment and cannot be repeated somewhere else. As evidence, he mentioned a variety of spring wheat, which had produced the highest yield under irrigation but the lowest yield in the dryland farming. Another example was the similar growth rate of some German wheat varieties at the -5 bar potential with some American varieties at -14 to -25 bar potentials (Kaul, ibid.). It is obvious that the drought tolerance of the American varieties could not have been realized in an irrigated treatment, the accepted practice of plant breeders!

As the main objective of such applied research is to solve the urgent problems which should lead to a sustainable agriculture for the desert inhabitants, it is essential to break the molds and follow the lines of thought which might differ radically from the conventional scientific disciplines. For instance, range managers prefer perennial forage to the annuals; therefore, they recommend that 40-50% of the crown cover should be saved from grazing so that their growth rate would be sustained in the coming years. As annuals may be grazed to the soil surface and FWS ensures soil water recharge in most of the lean years, the establishment of annuals should be encouraged at the cost of perennials if the lack of vegetative cover does not enhance soil erosion. This calls for a methodical study.

Having deep, extensively branched roots is a drought avoiding mechanism of some xerophytes. The carbohydrates diverted from the canopy to sustain root growth may be consumed in usable plant yield. The question is: What is the right shoot/root ratio for such plant species?

Water use efficiency (WUE) of the C4 plants is more than that of the C3 species. For example, WUE of sorghum is twice that of wheat (Dewit and van Keulen as reported by Fishcher and Turner, 1978). Is not growing Panicum antidotale Retz., a C4 forage (Tinus, 1974), and probably an N-fixer, more economical than growing alfalfa which has a very high rate of evapotranspiration? Could not we replace wheat and barely with sorghum as our staple food?

The above questions and many more wait for answers. It is only through painstaking research that we could eliminate such doubts. A few topics for research are discussed below. It is obvious that they are not exhaustive and more may be added to the list.

1. Identification of or Breeding for Wheat and Barley Varieties with Long Roots

As the concentration of "working roots" in the moist soil is a drought avoiding mechanism, breeding varieties which are more efficient in utilizing soil water and nutrients has been suggested a long time ago (e.g., Danielson, 1967). However, these roots should not be very active at the beginning of the growing season to absorb most of the available water, thus causing a lush growth, but do not leave enough reserve to supply the plant during the reproductive stage. Passioura (1972) has presented an interesting concept regarding the effect of root geometry on the yield of wheat growing on stored water. The xylem's resistance to flow is a mechanism by which water absorption rationing takes place.

2. Enhancement of Nutrient Absorption

A very interesting and advantageous property of floodwaters is the nutrients carried by them in solution or absorbed on the suspended load. The organic matter carried by floodwaters in the form of livestock dung or litter is another nutrient source. Composition of rocks on the watershed and their rate of weathering dictate the nutrient concentration in the floodwaters. A good example in this case is the concentration of nitrate and ammonium, which is on the average 59 and 23- ppm, respectively, in the floodwater of the Bisheh Zard Basin used for the FWS - ARG in the Gareh Bygone Plain, Iran.

As the surface soil is usually the most fertile part of the profile, and the active roots absorb nutrients to their potential, therefore, addition of fertilizers to the topsoil does not affect those roots very much. On the other hand, since mass-flow and diffusion supply almost all of the nutrients absorbed by the roots, and these activities are water-mediated, therefore, drying of the soil surface in the deserts deprives the plant of nutrients except those which are in immediate contact with the root hairs. This is very important in the dryland farming during the reproduction stages, thus points to the importance of placing fertilizers in horizons which are moist to the end of the growth period. Another alternative is the selection or development of varieties, which may absorb nutrients abundantly when the soil is wet and assimilate them gradually as the rooting-zone dries up. Selectivity of the roots for immobile elements is another desirable mechanism for rainfed crops. As nitrate leach to the lower horizons and potassium is sufficient in the soils of Iran we limit the discussion to phosphorus.

As P translocation towards roots takes place by diffusion (90-95%) and mass-flow (1%) in the soil solution (Barber, 1980), the presence of water is essential for P nutrition of plants. Therefore, as the soil surface loses its water P absorption by the roots gradually comes to a stop. However, since the deeper layers usually dry up later than the surface soil P absorption takes place there. Of course other mechanisms may be involved too.

Pothuluri et al. (1986) have shown in a laboratory experiment that hybrid sorghum-sudangrass absorbs more P from the subsurface layer than the surface soil when the P-supplying capacity of the former was high. Although droughty surface soil in dryland farming and irrigation with floodwater necessitate placement of P in the moist horizons, duplication of the cited research and that of Ozanne (1980, quoting Ozanne and Sewell) under FWS and with adaptable crops is recommended. Benefiting from the genetic potentials of certain varieties is another strategy.

Danilckuk and Yatsenko (Hurd, 1976) have reported that the 'Odessbaya' wheat has the potential to store P during soil water availability then consume it when the need arises. Apparently, Agropyron intermedium (Host.) Beauv. has the same characteristic (Viets, Jr., 1972). Trial of the known varieties suitable for cropping in the FWS system and breeding for special traits, which enables the crop to produce higher yields in such systems, is a research priority.

An interesting research topic is the nitrogen accumulation by the leguminous and nonleguminous pioneer trees planted in the FWS systems. Phosphorus and K transportation to the soil surface by these trees, along with a deeper rooting-zone in the sedimentation basins, prepares the land for cropping cereal (Kowsar, 1998a). Tree-cereal crop rotation is a good subject for investigation.

3. Crop Production in Fat and Lean Years

Contrary to the argument put forward by Adelman and Berck (1989), the Prophet Joseph's policy is still valid today in the deserts: Produce and store in the time of plenty and consume commensurate with the needs. This means cropping high yielding varieties in the FWS systems and hoping for the fat years. As these stocks require timely and sufficient irrigation, fertilization and pest and disease control, they show poor results when and where these inputs are lacking. On the other hand, local varieties, which are drought enduring, produce a respectable yield in the good years and some yield (more than the high yielding cultivars) in the lean years. Genetic engineering might resolve this dilemma by developing varieties that respond to flood irrigation but are not complete failure if floods do not arrive.

The artificial recharge of groundwater is a variation on the same theme where potential aquifers exist. Store waters underground and irrigate crops during the lean years.

4. Plants' Response to Sediment Deposition

Floodwater spreading on rangeland is not an unsullied blessing; turbid floodwaters may deposit thick layers of sediment on the spreaders. However, plants differ markedly in their response to sedimentation. Western wheatgrass (Agropyron smithii Rydb.) tolerated an annual silt deposition of 30-cm for 5 consecutive years (end of observation), while blue grama [Bouteloua gracilis (Wild. ex Kunh) Lag. ex Griffiths] could not tolerate even 25-mm of sediment (Hubbell and Gardner, 1944). Although eradication of poisonous whorled milkweed (Asclepias galioides H.B.K.) is advantageous due to sedimentation in New Mexico, USA (ibid.), barley and wheat seedlings cannot break through the hard crust formed by the fines deposited on them. Adaptability of local and exotic forage plants and agronomic crops should be ascertained. An important outcome of these experiments is the selection of suitable rhizomateous species for making a dense sod in the gaps, on the spilling sills and in the channels susceptible to erosion.

5. Weed Control

The seeds carried directly by floodwater or in the livestock dung are broadcast on the spreaders where they may grow vigorously. Although flood-mediated introduction of plant species into the FWS systems maybe advantageous, as the propagation of Artemisia sieberi Besser and Atriplex leucoclada Aell. in the previously loamy sand of the Gareh Bygone Plain in southern Iran has proven to be, one has to be concerned with the possibility of weed infestation of the system, particularly if food and forage crops are planted in them.

A thorough identification of plants on the watershed whose runoff or base flow is utilized in the FWS system is advised. Eradication of potential weeds, particularly noxious plants on the basin, may prove advantageous. Trifolium alexandrinum (L.) can eradicate many weed species in southern Iran. Other environmentally friendly techniques may be implemented to control weed infestation of the floodwater-irrigated fields.

6. Adaptability Trials of the C4 Species

As the C4 plants are efficient users of CO2 and water, their introduction into the FWS systems is a right move. Since these plants are adapted to the tropical areas where periods of abundant precipitation alternate with extreme droughts, thus they are able to compete with mesophytes in rainy years and still survive droughty seasons (Laetsch, 1974), their adaptability to the site of FWS should be tried. A very beneficial characteristic of some of these C4 plants is their symbiotic nitrogen fixation. Paspalum notatum (cv. batatais), Brachiaria humidicola and B.decumbens provided 20-45- kg N ha-1 yr-1 in Brazil (Miranda and Boddey, 1987); contribution of Panicum maximum Jacq. in the Brazilian summer (Dec. - Apr.) was 5-10- kg N ha-1.

As Panicum antidotale Retz., a possible nitrogen fixing grass(Neyra and Döbereiner, 1977), has shown a wide range of adaptability (it has survived the -14°C winter of Sabzevar, NE Iran) its trial in the FWS systems is strongly recommended. A short list of C4 plants is presented in Table 1.

Table 1. A short list of C4 plants (after Tinus, 1974; Berry and Björkman, 1980).

Family	Tribe	Species
Poaceae	Maydeae	*Zea mays*
	Andropogoneae	*Andropogon scoparius*
		Andropogon virginicus
		Saccharum spp.
		Sorghum spp.
	Paniceae	*Panicum antidotale*
		Panicum maximum
		Panicum miliaceum
		Panicum texacum
		Digitaria decumbens
		Digitaria sanguinalis
	Chlorideae	*Cynodon dactylon*
	Festuceae	*Eragrostis curvula*
	Agrostidae	*Sporobolus poiretii*
Graminae		*Spartina towensendii*
Amaranthaceae		*Amaranthus edulis*
		Amaranthus retroflexus
Chenopodiaceae		*Atriplex confertifolia*
		Atriplex lentiformis
		Atriplex nummularia
		Atriplex rosa
		Atriplex sabulosa
		Atriplex spongiosa
		Atriplex vesicaria
		Hamada scoparia
		Kochia spp.
		Salsola spp.
Euphorbiaceae		*Euphorbia* spp.

7. Macro- and Microbiology of the Floodwater Spreading Systems

Aggradation of environmental quality, an inevitable outcome of FWS in the deserts, provides a new medium for the invasion of adaptable macro- and micro- species. Appearance of truffle (Terfezia ssp.), three years after the installation of the FWS systems in the Gareh Bygone Plain in southern Iran, heralded a good turn in the life of a desert. Invasion of a sowbug (Hemilepistus shirazi Schuttz), 10 years after the start of FWS in the GBP, was the glad tidings for the designers and builders of the systems. This isopod, which forages on the leaves of Atriplex lentiformis (Torr.) Wats., a C4 plant, burrows deep into the sediment and facilitates infiltration into the very thick crusts (Rahbar and Kowsar, 1997). There has been a 5-fold increase in infiltration rate (IR) of the sedimentation basins following the sowbug appearance. We find it advantageous to plant this forage species and propagate sowbugs to keep an almost constant IR in the FWS systems. A thorough study of the micro- and macrofauna and flora of the FWS systems is recommended. Identification of mycorrhizae species is particularly important.

8. *Inundation Tolerance of Plants*

High infiltration rate (IR) is a great advantage in sedimentation basins and recharge ponds in the artificial recharge of groundwater (ARG) systems. As root channels formed by the deep-rooted, adapted species could maintain acceptable IR in the ARG systems, such plants should be identified and tried for utilization in the projects. Inundation tolerance, particularly for the young, short plants is a desirable trait. Furthermore, these species should be drought tolerant and survive long, rainless periods. Eucalyptus camaldulensis Dehnh., whose roots have been observed to a depth of 23- m at the Kowsar FWS and Aquifer Management Research, Training and Extension Station in the GBP, is a suitable species for mild and warm places. Alfalfa (Medicago sativa L.), which explore the soil profile to a depth of 10-m (Peterson, 1972) is worth trying. It is probable that Acacia salicina Lindl., which grows along with Euc. camaldulensis Dehnh. in the GBP, should have roots as long as those of that eucalypt.

9. *Water Balance of the FWS and ARG Systems*

As water is the most precious commodity in the deserts, and the FWS systems are usually planted to food crops and range plants, the evaporative demand of the crops intended for planting should be determined. This is especially important where no potential aquifer exists under the FWS systems, because irrigation beyond the rooting-zone in the nonsaline soil and with fresh water is the waste of water. On the other hand, planting of phreatophytes, where the ARG is the sole purpose of FWS, is contrary to the objective. As planting the deep-rooted species enhances the infiltration rate, therefore, one has to strike a balance between the advantages and disadvantages of having such trees in the system.

Shelterbelts and windbreaks offer many advantages including evaporation reduction; therefore, more water is utilized in transpiration. Establishment of windbreaks around wheat fields in the Kamennaya Plain of the former Russia increased transpiration rate from 48% in the control to 63% and doubled the yield (Lvovitch, 1971).

Irrigation of range grasses with floodwater should be matched with their water requirements, because species such as Agropyron desertorum (L.) Gaertner., Ag.smithii Rydb., Ag. trachycaulum (Link) Malte, Bouteloua gracilis Willd. ex Lag. ex Griffiths and Stipa viridula Trin. do not use as much water as legumes and pasture grasses, thus storing large amounts of water in the soil for them is the waste of a precious commodity (Fairbourn, ,1982). Therefore, it is better to spread a limited amount of water on a larger tract and produce more forage.

10. Carbon Sequestration

Global warming, mainly through the production of the" greenhouse gases", specifically CO_2, has attracted the attention of concerned individuals to the role of vegetative cover in carbon sequestration. As forests, with their relatively long lives, can store large amounts of CO_2, their protection and expansion have become a worldwide environmental priority. Eucalypts(Eucalyptus spp.) offer a potential plant material for ameliorating the environment through carbon sequestration.

A very high rate of survival and a considerable rate of growth of Eucalyptus camaldulensis Dehnh. in the Gareh Bygone Plain(GBP) in southern Iran have made this species the tree of choice for CO_2 sequestration. Survival rate of this tree at the age of eight has been 86%. The annual increment of the same has been 7.76-m^3ha^{-1}. Assume that these two values are valid for a 10-year coppice rotation (Kowsar et al., 1996). Further assume that 70% of the yield is stemwood. Therefore, approximately 50 tons of CO^2 are taken out of circulation by the wood industry, and semi-permanently removed from the atmospheric pool from each ha every 10 years.

Probably the same amount is also sequestered in the roots. These need to be quantified and used as a commodity in the international market of the clean environment.

11. Phytoremediation

Phytoremediation, to paraphrase the American Academy of Microbiology, is the use of plants to reduce or eliminate environmental hazards resulting from accumulation of toxic chemicals and other hazardous wastes. Eucalyptus camaldulensis Dehnh.,an evergreen tree with no apparent rest period, has proven to be an excellent NO_3 and NH_4 remover from an alluvial aquifer in an ARG system in the GBP in southern Iran. The roots that occupy the entire 23-m thick vadose zone consume some of the dissolved and exchangeable NO_3 and NH_4, thus help to decontaminate the water (Mohammadnia and Kowsar, 1999). This is a fertile area for further research.

12. Resource Use Optimization: Establishing Desert Utopias

Water is the scarcest commodity in the deserts. Arable land is going to attain the same status by the end of the 21st century, if not sooner. Therefore, if the Homo sapiens are to continue inhabiting the planet earth they have to optimize the use of resources at their disposal. Large cities, with their peripheral slums that are mostly occupied by the landless peasants and nomads, are fast losing their urban qualities. Deserts are the last resort for the people who desire to inhale fresh air and enjoy their daily activities without the fear of being run down by the urban malaise. The Desert Utopians realize that their survival depends on respecting the natural resources. Water will replace money in our Desert Utopias. Water will be valued according to its availability, purity, temperature, subterranean flow rate and other attributes. Water – use optimization is the key to the Desert Utopias'continuing prosperity.

A hydro-agro-silvo-pastoral economy–not necessarily in that order– is the tenet of our Utopias. We have to do whatever possible to conserve the available water and keep it clean. Utilization of solar and wind energies are but only two of the mechanisms which could replace fossil fuel-produced electrical energy with all its pollution potential (Kowsar, 1998b).

13. Animal Husbandry

Although eucalyptus species are notorious for their unpalatability, livestock browse their leaves and twigs in the Gareh Bygone Plain, Iran, particularly those of Eucalyptus camaldulensis Dehnh. with no apparent ill effects. As feed production is vital for the herdsmen in the deserts, and this species leafs profusely, inclusion of its leaves in the livestock ration requires investigation. Fodder trees, such as Acacia salicina Lindl., Ac. cyanophylla Lindl. and Ac.victoriae Benth. could carry a limited number of livestock in severe droughts. However, we know very little about the longtime effects of consuming the meat products raised on these species.

Acacia salicina Lindl. is in flower from October through March, and provides nectar and pollen for honeybees. Very few plants are in flower during fall and winter in southern Iran. As eucalyptus, other acacias and native vegetation are in flower for spring and summer apiculture should be considered as an important enterprise in the FWS systems in the warm environments. As the extreme summer heat is a deterrent to raising the exotic breeds, the local (wild) bees should be studied, and if possible, domesticated. Various combinations of pollen and nectar producing species should be tried for concocting different flavors and tastes in honey.

14. Environmental Quality

Stagnant waters in mild climates make excellent breeding ground for anopheles mosquitoes that transmit malaria. Some freshwater algae produce odors and taste, which decrease the drinking water quality (Nightingale and Bianchi, 1977). Farmers do not appreciate the birds and rodents, which gather around the standing water. Although none of these might materialize where floodwater is used in the ARG systems, one should beware of the problem if the rainfall regime leads to a prolonged base flow utilized for the artificial recharge (e.i., Ziaran, Qazvin. Tchenaran, Khorasan). The above mentioned problems might happen in the clogged recharge ponds too. As pesticides and herbicides adversely affect the water quality their use in the ponds is prohibited, certain species of fish, which forage on the aquatic plants, and mosquitofish (Gambusia affinis) that eat the larvae should be released into the problem areas.

Sociological Studies

Provision of clean water and sanitation in the "Decade of Water" (1980-1989) to every corner of the world is a long way off. Sedentarized nomads, who used to chase stagnant waterholes, should develop a special attitude in groundwater utilization, grazing of flood-irrigated rangeland, and particularly maintenance of the FWS systems and woodlots. It takes years before these excellent herdsmen become average farmers. A thorough and deep understanding of their traditions and values are required if they are to manage the FWS systems that the governments provide for them. Our 18 years of experience in the Gareh Bygone Plain, southern Iran, has shown that there is no short cut in communicating with these free souls!

1. Economic Justification

As social dividends of floodwater spreading, particularly for the artificial recharge of groundwater, far outweigh monetary gains, discussion of economic feasibility may sound irrelevant (how much does a human being drowned by flood is worth?). However, as the government authorities, who approve and finance the projects, and the people whose way of life might be disrupted by the new methods of doing things, must be convinced of the soundness of a proposed plan, a thorough study of an operating project helps them to decide on the merits of FWS in certain areas. Book keeping on the expenses and incomes, particularly the volume of water diverted and the benefits accrued in flood mitigation and employment opportunities, could be a great help in convincing the skeptics (Kowsar, 1991; Bakhtiar et al., 1997ab).

2. Land Ownership

Although self-help is a crucial element in our desertification control strategy, convincing sedentarized nomads, even some farmers, to pay for the FWS systems, or to contribute their manual labor for their construction, is very hard indeed. They usually claim that since the land is not theirs, therefore, they do not waste their resources on an uncertain enterprise. However, as soon as the "wasteland" becomes arable and its aquifer productive following the implementation of ARG on it, the very same people claim ownership! This is a very sensitive problem and requires legislative actions; Therefore, legal minds should devote a considerable amount of time to it and develop an equitable law that could be enforced with a minimum of hustle.

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14

Integrated Land Management in Desert margins in Niger
A Research Proposal

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Overview

The participative research project on integrated Land management in Niger is a program of collaboration between institutions such as the Institut National de Recherche Agronomique du Niger (INRAN), Energie et Environnement pour le Développement Rural (EDER) and the United Nations University.

The project consists of improving food security and contributing towards the fight against desertification on the basis of systems of using the lands in the marginal desert zone. The desert margins in Niger are less favorable potential areas where a large majority of population lives.

The program site concerns the northern area of Tillabery grouping together the areas of Téra, Tillabery, Ouallam, Fillingué with a population of 1,386,290 inhabitants and an area of 70,000 km^2 or 1.5 times Togo, and more than half of Benin. The area is distinguished by the prevailing ice Lands (47%), damaged plateaus and slopes (21.5%) uncultivated dunes (20%) and some valleys (11%), pools (0.5%) and alluvial terraces, more than 150 km with 4 tributaries and more than 40 rivers covering the Niger river with sand. Food security in this area is strongly affected by climate change, population growth and by a general degradation of water and Land resources.

Presently, the research has only modestly contributed to solving the poor population problems. The technologies developed by the national and international institutions working in Niger face difficulties reaching the users. The project will contribute to a better management of water and land resources by building the capacities of stakeholders, with technology development and improved water and Land resources management, the necessary multidisciplinary information by reinforcing the capacities of national research institutions and farmers organizations in Niger.

The participative research project on integrated Land management, subject of the present study, comprises two main activities closely related:

1) Participative research in farmer's environment
2) Capacity building and information management

The research concerns the developing of adapted and sustainable technologies in the field of water and Soils conservation/Defense and Restoration of soils (CES/DRS in French) in Various agro-ecosystems of the above-mentioned areas. The capacity building axis will emphasize training and dissemination of research results particularly to researchers, farmers and decision makers. The information management axis aimed to reinforcing the flow of information between the research, the decision-makers, the technical services, the NGOs and the farmers through a better communication on both sides and more efficient management of data.

The project has been worked out by taking account the objectives of the policy of the Government of Niger namely "the National Action Program for Desertification Control and Natural Resources Management" and the research program of INRAN on Desert margins.

Introduction of the Project

Sahelian Region

The Sahalian zone of West-Africa stretches from senegal to Shad and is located between latitudes 10 and 14 degrees North. This arid area represents 77% of the total land areas. It consists of high spatial variability in natural resources and ecosystems. The physiography is characterized by large, parallel fossil dune ridges dominated by herbaceous vegetation, inter-dune areas with predominantly solonetz soils with typical Sahelian Acacia Savanna and wetlands on vertisols in the lowest laying areas. The flora in these Sahelian specialized plants that do not grow on the other units, with light sandy soils (arenosols) having the highest number of specialized species. The ecosystems are dominated by xerophyte and phanerophate plants, which demonstrates the unique adaptation of the ecosystems to the prevailing dry conditions. Rainfall variability in climate and ecosystems results in high temporal and spatial variability in biomass production, which is reinforced by cultural and socio-economic diversity in managing land and natural resources. Rural livelihoods are mainly based on transhumance pastoralism and small scale agriculture. The transhumance and cattle routes follow traditional patterns that cut across national borders.

The Project Zone

The Northern of Tillabéri area is located in the Province of Tillabéri; between 13° 30'N and 15°45'N latitudes, 0°10'E and 4°20'E longitudes. The Province is composed of four (4) northern districts namely Fillingué, Ouallam, Tera and Tillabéri with 70, 000 km^2 area and a population estimate about 1 million inhabitants represented in 2,899 villages and hamlets.

The project zone comprises the four Northern districts of Tillabéri Province which cover an area of 6,877,011 hectare (68,770 km^2), as shown in Table 1.

Table 1. Areal distribution in project zone

Physiographics	Area (ha)	Percentage
Glacial	3,197,899 ha	46.50%
Sand and complex dunes	1,385,430 ha	20.15%
Slopes	752,812 ha	10.95%
Valleys	728,166 ha	10.59%
Plateau	700,556 ha	10.19%
Hills and rocky crest	72,937 ha	1.06%
Pools and depressions	29,599 ha	0.43%
Other units	7,190 ha	0.10%
Alluvial terraces	2,422 ha	0.4%
Total	6.877.011 ha	

The northern zone population of Tillaberi grouping the areas of Tera, Tillaberi square, Ouallam, Fillingué, whose population is estimate to 928,128 inhabitants (457,223 of men and 470,905 of women) represented in 2899 villages and hamlets according to the General Assessment of Population in 1988. By using the national rate of annual growth of 3.4%, the number of inhabitants would be of 1,172,874 in 1995 and will reach 1,386,290 in 2000.

Some strong human concentration observed along Niger river and in Dallol zones where the population density is very high and the growth rate varies between 4 to 5% in places where an important migration rush derives. It is also notified that the northern Tillaberi population is very young, 77% of this population has less than 30 year and 44% are aged below 10. The zone is located between 250 mm to 400 mm ishoyet. From 1950 to 1999, many variations have been notified. The calculated temperature on an average of 28 years (1951-1988) knows for example in Tillaberi a minima of 22.6°C and a maxima of 36.8°C.

Land Degradation

Due to increasing pressure on the land and inadequate policies that have hindered the free mobility of pastoralists in the region, land degradation symptoms are numerous and include wind erosion on dune crests, sheet erosion in inter-dunes and sedimentation and siltation of wetland, including oasis and water courses. More importantly, the impact of land degradation entails reduced productivity of range and agricultural land, which force people to open up new, often even more marginal lands to sustain their livelihoods, such as removal of nutrients and reduced water-holding capacity of the soil, is a long term threat to all plant growth, but particularly to highly specialized and sensitive plants. For example, herbaceous plants such as Schoenfeldia gracils and Panicum laetum are being replaced by less sensitive plant such as Aristida. The siltation of Wetlands and watercourses does not just constitute a threat to plant and animal biodiversity, but also deprives local people of water for drinking and sanitation, as well as irrigation.

Project Objectives

The project objectives include the following:

- To survey land resource management practices found in the region;
- To assess the extent of degraded Land and other resources in these areas for possible intervention;
- To improve adapted environmentally-sound technologies for water and soil management to farmer's conditions in Desert margins;
- To evaluate rain water harvesting as a means of increasing productivity per unit cropped area and per unit of labour;
- To determine the effect of land forms on water availability and rainfall use efficiency in the arid zone;
- To improve the flux and exchange of information between the researchers, decision-makers, farmers on both sides.

Research Project Components

The research project shall have three main Components which be carried out in three phases :

A. Survey of Existing Land Management Practices

The role of the indigenous knowledge system in the implementation of rural development projects had always been taken for granted. The local people know their soils, water, crops and animals better than anybody else and have developed coping mechanisms to ensure, to the best of their ability, the sustainable use for their natural resources.

It is proposed that the first phase of this project shall involve a survey of existing land management practices (both indigenous and exogenous). This will also involve taking stock of plants and livestock species and numbers respectively. This is with a view to identifying areas where research intervention will be most appropriate. This survey shall be carried out the four regions of the project site in arid lands of Niger from south-west to the northwestern. The participative rural appraisal methodology shall be used for this survey.

B. Survey of Degraded Lands

Vast extent of degraded land abound in the drylands in Niger. Unfortunately, the natural hectarage of degraded lands in the project site is to be determined. It is therefore proposed that the second phase of research project should be devoted to a survey of degraded land. This survey shall also cover the four regions of the project site. It shall involve both field work and the use of existing data. For this purpose, the GIS facility of INRAN shall be fully utilized. Necessary maps shall be sourced as appropriate.

C. Field Studies on Water Harvesting/Defense and Restoration of Soils Techniques

The productivity of arid lands in Niger may be greatly enhanced through :

- Optimization of the use of the available rainwater through appropriate water harvesting techniques.
- Improvement of adapted environmentally-sound technologies for soil management to farmer's condition.

- Adoption of cultural practices that will increase the soil organic matter content.

This phase of the project will also involve the use of organic fertilizers (eg. Compost, Farm yard manure). These studies shall be carried out in two regions. These are Ouallam and Fillingué areas. In each region, three farming communities shall be selected for the field studies. Appropriate landscaping treatments shall be imposed. These field studies shall be carried out on farmer's fields in order to facilitate adoption of technologies arising there of. Preparatory to the fieldwork, relevant staff of Agricultural Development Program of each Province covered by this study shall be selected to participate in a training workshop on water harvesting/Defense and restoration of soils, and organic fertilization. New water and soil management practices will be tested on farmer's fields as part of the trials. It is hoped that such trained staff shall participate in the conduct of the field studies.

Project Methodology

This participative research project shall be carried out with the involvement of the grassroot skakeholders who will participate in site selection, project implementation and project monitoring. It is hoped that this bottom-up approach will facilitate the dissemination and adoption findings arising from the project. A number technologies developed or adapted in the field of soil and water conservation, defense and restoration of soils in Niger are shown in Table 2.

The research will cover the following areas :

Integrating management of soil fertility

- Quantitative establishment of mineral assessment in differents systems and agro-ecological zones;
- Regeneration of soil by the natural phospahates and organic fertilizers; and
- Research in order to add the efficiency of nutritious elements.

Water and Soil Conservation

- Constitution of a data base on the traditonal and modern technics of water and soil conservation;

- Interaction study of these technologies on the utilization of nutrients; and
- Agro-economic quantification of anti-erosive measures

Agro-forestry

- Identify the adapted ligneous species to the different agro-ecological zones and farmer needs for a best preserving and maintain of soil fertility;
- Management of trees and small shrubs in the villages for a best quality and quantity of fodder for animal; and
- Exploitation of micro-elements effect and high fertility under Acacia albida for crops diversification.

Establishment of a Data Base on the Natural Resources

- Socio-economic characterization of villages;
- Lands use type and resources use in the management areas;
- Difference between men and women in allowance and natural resources use;
- Labor availability;
- Growing systems;
- Livestock management;
- Traditional practices of soils improvement; and
- Farmer income sources resulting from the farm and outside.

Political effects (macro-economic intervention) on technology adoption

- Credit;
- access to markets;
- rural infrastructure;
- dissemination service; and
- alternative options research of agricultural politics for an environmentally-sound technology adoption.

Information Management and capacity building

This phase is complementary to the scheduled research activity. The scheduled activities are directly related with the participative research. The constraints can be found at multi-levels :

1. The users information needs are not recognized at research level;
2. Bad communication between researchers;
3. Ignorance, or even negligence in the research of the local data sources as well at the farmers level as at the community-base organization level and some development projects;
4. A relative inaccessibility of different data base existing in Niger and the exchange difficulties between the information sources.

A national workshop shall be organized at the end of the project to facilitate input of categories of stakeholders into the project report and to help disseminate the same results. Publication of the results will also be done in appropriate journals. Manuals in French, Djerma and Hausa, the three most popular languages spoken in Niger. Following similar studies in Tunisia or other regions, a regional workshop shall be organized to exchange research information and to help network development in the regions

Expected Output

- The project is expected to catalog the various land Management practices obtained in this arid zone of Niger and their contribution to land degradation
- It is expected that a model will be developed at the end of the studies for use in prediction the effects of water harvesting on crop and range production for different rainfall patterns and soil types
- The cost-effectiveness of water and soil conservation technology for the region will be updated in the light of changes in precipitation of the areas
- Recommendations on sustainable land management practices for the region
- Capacity building for the participative Institutions, NGOs, agencies and Community-based Organizations.

Table 2. Technologies developed or adapted in the field of soil and water conservation, defense and restoration of soils in Niger

Technologies	Sphere of activity	Targets	Performances	Application fields	Application limits
"Demi-lune"	Management of natural resources, soil and water conservation, defense and restoration of soils	- Harness runoff from the river basin to increase the quantity of available water for vegetation - Hold up erosion and trigger off sedimentation by obliging the runoff to leave a part of its load.		Demilune is built on elevated plains lands and glacis with weak slope at 1 to 3% in areas of low rainfull for agro-silvo, silvo-pastoral or simply forest production	- Risk of plants asphyxiation due to excess of water ; - Not indicated for arenaceous soils
Refor-estation trenches	Management of natural resources, agroforestry associated with the recovery of runoff on high slopes	This technique enables to recover runoff on high slopes before starting the reforestation of rocky valleys	This technique enables to store a volume of water varying from 1 to 2 m^3. It thus enables to increase ligneous and herbaceous biomass together with biological diversity.	The technique is adapted to grounds with high slopes, rocky valleys and naked glacis. It enables the silvo-pastoral reforestation of rocky valleys at the rate of one tree per trench.	- painstaking work requiring strong workforce - highly costly technique (110 $ US/ha)
Silvo-agricultural banks	Technique used in agroforestry associated with water erosion control and recovery of runoff	The silvo-pastoral banks aimed at reducing wind erosion, favoring the infiltration of runoff, recovering and rehabilitating elevated plains more or less dead and glacis in order to make them opportune for silvo-pastoral production	-increase in the production of biomass and biodiversity, -strengthening of the soil pattern; -change of the surface runoff at the level of the watershed; -improvement as regards rainwater infiltration	The technology is adapted to lands of deteriorated elevated plains and glacis.	-this technology is not appropriate to areas with constant rainfall gap; -emergence of conflicts between farmers and cattle breeders with regard to the management of the treated zones.

Technologies	Sphere of activity	Targets	Performances	Application fields	Application limits
Low walls	Management of natural resources : erosion control and runoff recovery	Break the speed of rainwash, favor infiltration and ensure soil deposit upstream	-protection of land upstream ; -increase of biomass; -increase of lands suitable for cultivation	This technology is applicable on naked slopes of exploitable lands for rainy season crops or on rocky soils slopes that can produce grazing land	The implementation of this technique requires some physical effort and some quantity of stones.
Stones bars and bundwalls	Management of natural resources, agroforestry associated with erosion control and runoff recovery	Increase production through the reduction of water erosion, enable the soil to acquire some stability with regard to the distribution and flow of waters throughout fields		Works recommended on elevated plains, glacis with weak slopes exploitable for rainy season crops	-availability of stones and transportation means; -need to mobilize populations.
Biological protection of banks and koris	Management of natural resources : water erosion control	Wind erosion control to enable stabilize the banks of the gullies without blocking the spreading of water on soils	-fixation of the banks of the gullies threatened by water -production of biomass -increase of biodiversity	This technique is adapted for the treatment of gullies and trenches of less than 1m deep	This technique is expensive and require a strong mobilization of farmers for planting activities together with a technical and external support for the production of plants.
"Tassa or Zaï"	Recovery of soils, fertilization, water management	-Recultivation of deteriorated lands -Increase in the potential of farming lands -Increase in the use of rainwater -Preparation of the land for direct seedlings of woody and herbaceous species		-glads soils; -lateritic elevated plains lands; -millet, sorghum and maize crops; -woody and herbaceous crops	-the technique does not adapt to arenaceous soils -availability of manure, transportation means and labor -the technique requires a renewal every three years

Technologies	Sphere of activity	Targets	Performances	Application fields	Application limits
Restoration of deteriorated areas for silvo-pastoral projects	Recovery of soils with a silvo-pastoral calling	Restoration of deteriorated areas for silvo-pastoral actions	-life duration : 5 years; -norm : 2.5 ha/hour; -production of straw the first year; -production of firewood as from the 3rd year	Elevated plains and glacis	Technology requiring heavy machinery
Mechanized trenches	Management of natural resources, soil and water conservation.	-harness runoff for the development of vegetal, herbaceous and ligneous species -harness transportable elements by wind through sedimentation (sand, seeds, etc.) -break the crust of hard soils	Quick recovery of large deteriorated areas, requires heavy machinery (tractor + valarini plow).	Mechanized trenches are made on lands, elevated plains, watersheds with weak slopes, glacis in areas of low rainfall	Risk of asphyxiation due to excess of water

Source: Institut National de Recherche Agronomique du Niger (INRAN)

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Water Utilization and Management in the Tarim River Basin of Arid Region, China

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Introduction

In the arid region, the water is the most important natural resources. The development and management of water resources are not only directly related to the development of agriculture, prevention of environment, but also closely geared to the development of the arid region economy. Therefore the water resources management has been attracting more and more attention from the region governor to local farmer. But due to the increased intensity of human activities and overused or misused the water resources, the problems such as salinization, vegetation degeneration and desertification, were caused and developed quickly for last decades. The water resources already take on a great pressure for agricultural production in the arid regions at present, and will faces much more difficult situation in the future. So to understand the relationships between the water and environment, water and development, to recognize how to practice sound water management, are crucial important projects for sustainable development and stable environment in the arid regions.

Taking Tarim River Basin as one of case study, this paper deals with the eco-environmental changes caused by water use, evaluation and management of water resources in the arid region of China. The Tarim River is the biggest inland river watershed in the arid region of China, which is situated between the Tianshan Mountains and the Kulum Mountains in Xinjiang Uygur Autonomous Region. The Tarim River Basin is a complete ecosystem unit in which surface water and ground water are closely interrelated. The renewable water in the basin is not only an important natural wealth for coordinating the distribution and development of agriculture, forestry and animal husbandry, but also a significant factor for maintaining natural ecological balance and protecting environment. Water development and utilization have been affected the scale of oasis in middle reaches of the river and the existence of the lower reaches. So far, there are many negative impacts, caused by poor management of water utilization, not only for environment but also for social-economy. For example, the salinization was caused mainly by the overuse of water in the upper and middle reaches of the Tarim river, meanwhile the sandy desertification spread in the lower reaches because there was no water supply any more. Therefore the most pressing task for the

Basin is to work out comprehensive planning, considering the whole Basin as an unit, to distribute and use water resources in the upper, middle and lower reaches in a planned way and starting out from economic, environmental and social benefits to achieve rational management.

Water Resources and Utilization

The Tarim River lies along the northern part of the Tarim Basin. The main water supply come from the Yarkant, Hotan and Aksu River. The river length is about 1 280 km up to the Tatima Lake. The average annual runoff of the river totals nearly 5,000 billion m^3 in which the Yarkant River accounted for 5.5%, the Hotan River for 22.5% and the Aksu River for 72.0%.(Xie Xiangfang, 1989). But at present, the Yarkant River has become an non-perennial one, the Hotan River become a seasonal one and only the Aksu River provides water during the whole year. There are some characteristics of runoff in the River as following:

1. The runoff changes with the upper water source and its consumption along the river. If the amount of upper water is less and the consumption is more, the runoff is less; and vice versa.
2. The seasonal distribution of water is highly centralized. The Tarim River originates chiefly from flood and recharge water from upper irrigated areas.
3. The fluctuation of runoff is sharp day to day and year to year.

But anyhow, endowed with rich water resources, the large area along the Tarim River have been reclaimed and cultivated for long time. According to archaeological data, since as early as the New Stone Age, the area had been opened up gradually along with the development of primitive agriculture and animal husbandry. Many cultural relics can be found around the marginal areas of the Tarim River Basin, which prove to the period of early water use of the ancient society between 10,000-3,000 years B.C. The human influence on the water and land increased since the economic pattern changed from hunting and gathering to cropping. There were more than 10 000 population in the Loulan ancient city at 2,000years B.C. During the Han Dynasty (206 B.C.-220 A.D.), the central government had have garrison troops, and peasants opened up wasteland and grew grains in Luntai. A large scale irrigation system with channel of more the 50 km in length, constructed during Han Dynasty, was discovered in the southeastern part of Xayar County. Up to Tang Dynasty (618-970 A.D.), the irrigation agriculture obtained further development as the area of farmland expanded and the settlements were full of life in many natural oases so that many towns and cities could left their name along the Silk Road. The irrigation works and cropping agriculture made great advances during the Qing Dynasty (1644-1911).

Since the 1950's, along with the pressure of population growth and expansion of production, the area of cultivated land has developed gradually. The population has increased from 4.33×10^6 in 1949 to 14.0×10^6 in 1988, and the cultivated land has increased from 1.2×10^6 ha. in 1949 to 4.0×10^6 ha.in 1988 in Xinjiang. In the catchment of the main rivers of upper reaches of the Tarim River, the farmland expanded 300,000 ha. more, which consumed much more water resources than before. In brief, the water use was tremendous. It has provided all of agriculture production and proved a decisive effect in improving the well-being of the people and developing the economy in the Tarim Basin.

Some Problems Caused by Water Utilization

In the arid regions, the natural oases can be considered as a special ecosystem. The formation and development of every oasis are depended on water supply from the river. Along with the increase of cropping land and the productivity, it has become necessary to reallocate the water resources. As a results the periphery of oases was exploited and a new ecosystem was formed. This is the process of formation of so called artificial oases, which transformed and replenished the natural oases. But if the water resources had been overused and misused, which means the human activities were not coordinated with the natural environment and exceeded its carrying capacity, the environment will be degraded to unfavorable conditions for the human sustainable development, such as the spread of the sandy desertified land and salinization land.

Natural Vegetation Degeneration

There is a fragile ecosystem along the Riverbanks, where natural vegetation is adopted to the changes of the Riverbeds. The water is the decisive factor to the ecosystem, which will affect directly the environment by the changes of water quantity, quality and regional distribution. There were 106×10^6 ha. cropland in the Tarim Basin and most of them were located in the upper and middle reaches of rivers. Because more than half of the cropland was opened up since 1950's, much water was used in the upper and middle reaches, so that the water supply decreased or even stopped in the lower reaches of the river. Before 1950's, the Tarim River had enough runoff so that a large lake, the Lop Nur Lake with more than 3,000 km^2, was formed in the end of the river system. But during the last 5 decades, due to the development of agriculture and the sharp increase of the water consumed for irrigation, the water supply to the lower reaches had decreased constantly. An artificial Daixihaizi Reservoir becomes "the end of lake". The lower reaches from the Tikanlik had received less and less runoff from upper reaches decade by decade as follows: 8-9×10^8 m^3 in 1950's, 3.6×10^8 m^3 in 1960's, 0.55-1.09×10^8 m^3 in 1970's, much less in 1980's and almost 0 since 1990's. More than 300-km length riverbeds dried out for many years. The ground-water level of the both sides along the Tarim River declined quickly from 3-5 m to 8-10 m or more. Without enough water supplies from both surface and ground, a vast area of the woodland, which distributed along the river and was mainly composed of Populus diversifolia, had disappeared. The rangeland degradation was also caused by the shortage of water supply and by the over-grazing.

Sandy Land Desertification

The sandy land desertification is a major part of degradation along the Tarim River, especially in the lower reaches of the river. Based on the analyze of remote sensing data in 1959(air-photo), 1983, 1992 and 1996(satellite data), we can find that the annually average spread rate of sandy desertified land was about 0.24% from 1950's to 1990's (Wang, 2000). Along the lower reaches of the river there were many areas of farmland, which had to be abandoned because the water supply had been cut off. Those areas were subject to be eroded by wind and become to the desertified land in some years later. For example, only in 5 state farms in the lower reaches of the Tarim River had discarded 8 600 ha. since 1970's. In Hotan region, more than 30,000 ha. farmland were desertified after they have been given up. The total areas of such desertified land were 3,430 km^2 and most of them was formed since 1950's in the Tarim Basin. Since many areas of woodland and rangeland had been degraded, the oases along the Tarim River have lost the windbreaks system. The wind erosion not only harmed the farmlands and oases, but also endangered the former woodlands and rangeland themselves. In this case, most of the shifting sand comes from those areas, which were suffered from, wind erosion. In the Tarim Basin, about 840 km2 of desertified land have been developed from this process during last century (Zhu, 1987). Since most of the oases face the desert in the Tarim Basin, it is very difficult to protect the oases from the movement of shifting sands and the encroachment of dunes, although some efforts have been made in some areas. About 1,300 km^2 land have been degraded by this process during last century.

Land Salinization

Those areas, taking the advantage of along the Tarim River, relied on the better supply of water resources in the upper and middle reaches of the river, have been cultivated from woodland and rangeland to cropping land in a large scale. For example, only during two years of 1957 and 1958, some 72,000 ha. wasteland had been claimed, 5 reservoirs and 17 state farms had been established along the Tarim River. This enable 122,000 ha. or more cropland to be irrigated. Although the wasteland in the Tarim Basin can be transformed into good farmland through drainage works and desalination, rotation of crops and fertilizing, yet it is easy to lead to salinization due to an acute change of water and salt movement resulting from careless water management. It is a common problem in many irrigation areas along the Tarim River. In the irrigation system, the utilization coefficient of canal water system was low, although a great quantity of irrigated water was supplied to the fields. This was a major reason for leading to a large quota of irrigation. The irrigated method was also poor like as the flood irrigation, so the gross quota of irrigation was more than 16,000 m^3/ha. and in some areas more that 22,500 m^3/ha.. Such practice not only wastes the water resources but also can't meet the water need for crops in the good time and quantity. This has resulted in the raising of groundwater level, leading to the creation and expansion of the land affected by salinization. A total of 751,000 ha. farmland in the Tarim Basin was affected by the salinization and more than 72% of those areas, about 5,410 km^2, have been salinized in different degrees.

Water Management of the Tarim River Basin

The farmland and rangeland along the Tarim River is endowed with enough water resources and rich light-heat resources; the natural conditions are quite favorable for the development of regional economy. Although the water utilization has achieved many good results and has greatly contributed to the socio-economic development and people's living standard, there are some serious environmental and economic problems, which has been caused mainly by the unceasing pressure of population and overuse or misuse of water resources, we have to overcome.

Based on the evaluation, some suggestions can be made for improving the water management and combating the land degradation of the Tarim River Basin.

1. To reasonable use the water resources along the whole River. That means to harness permanently the upper reaches, to improve gradually the middle reaches and to ensure the protection of the lower reaches. The first is to control the water utilization of the upper reaches and to increase the potentialities of water source for production and to ensure water supply into the lower reaches for ecosystem mostly. The second focuses on adjusting the structure and distribution of production, making water transportation getting on well, and reducing the loss of water. The third one is to recover the stream water, to keep the ecosystem balance.
2. At present, the environment of the lower reaches is deteriorating from the result of dropping level of ground-water, increasing degree of mineralization, declining nature vegetation and expanding desertified land. The so called "Green Corridor" is facing with the danger of being engulfed by shifting sand. Therefore, ensure the protection focus on conveying water to the lower reaches to promote forestry recovery and regional economy development. With adopting an overall point of view, it is necessary to ensure

minimum water supply for maintaining the balance of ecosystem in the lower reaches even if the upper and middle reaches are suffered from this. The policy of management is to consolidate the upper section, recover the middle section and construct the lower section. The schedule is to proceed the east region of highway first, then the west; to follow in order and advance step by step. The measures are to protect and recover the natural vegetation as focal point, and to plant grass and tree or adopt some physical reform way in certain section.

3. Related to several prefectures, the management of Tarim River should weight all advantages and disadvantages and make a plan with due consideration for all concerned for developing regional economy, managing environment and allotting water. A strategic decision can be made by operation research.

Conclusion

Water resources in the Tarim River Basin are very favorable for comprehensive development of agriculture, forestry and animal husbandry. But due to the increasing population and scale-up economic activities in the region, the water resources would be limitation if the traditional pattern of water utilization still had been practiced. To increase potential of water resources depends upon introduce new saving technique, such as spreading-dripping irrigation and green house, to enhance water availability and reduce ineffective evaporation.

Former utilization of water resources in the Tarim River has changed the hydrological conditions from surface water system, ground-water table to water quality and quantity. and to influence the Basin environment. Despite the areas at upper and middle reaches obtained more economic benefits by increasing water consume, but there was environmental degradation such as salinization, vegetation degeneration and sandy desertification in the middle and lower reaches. For this reason, water management must be in harmony with two major objective of economy development and environment protection. A special feasible measure should be carried out to maintain the lower reach oases.

The important task to the water management in the Tarim River is to ration water allotment from upper, middle to lower reaches. The key to implement water allotment scheme is engineering construction, such as to establish large trunk adjustment and storage reservoirs and delivery channels. At present it is necessary to put water conservancy projects as quick as possible into and overall development and comprehensive model of the Basin, which already set up an overall engineering system of water resources. Rational utilization water and land resources are closely related and promoted each other. Water use have affected the construction of oases scale in upper and middle and possibility of existence oases in lower reaches. Therefor, it is urgent to limit the construction scale of oases in upper and middle section of the river, to establish artificial irrigation system, to strength protective system of oases. Based on sound water management, we can develop and establish gradually a better Tarim River Basin with high production and economic benefit, stable ecosystem and favorable environment.

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16

Desertification in the Tunisian Jeffara - Convenient Uses of Soils and Water Resources and Control Techniques

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Introduction

Desertification is a land degradation problem of major importance in the arid regions of the world. Deterioration in soil and plant cover has adversely affected nearly 50 percent of the land areas as the result of human mismanagement of cultivated and range lands. Overgrazing and woodcutting are responsible for most of the desertification of rangelands, cultivation practices inducing accelerated water and wind erosion are mostly responsible in the rain-fed croplands, and improper water management leading to salinization is the cause of the deterioration of irrigated lands. In addition to vegetation deterioration, erosion, and salinization, desertification effects can be seen in the form of loss of soil fertility, soil compaction, and soil crusting. Urbanization, mining, and recreation are having adverse effects on the land of the same kind as is seen on range, dry farming, and irrigated lands. Combating desertification can be done successfully using techniques already known if financial resources are available and the political will to act is present.

Project Objectives

General Objectives

- In the context of desertification, to study in a basin compartmentalized from the uphill to the downstream in segmented agricultural landscapes, the problem of the access to soil and water resources, while considering water as a privileged agricultural, socio-economic and environmental evolution vector.
- To provide tools to the decision-maker to choice the mains amenities and actions of struggle against the desertification based on the integration of strategies of the different groups of actors and on their regulation capacities.

Scientific Objectives

- To identify interactions between the evolution of resource utilization method, production systems and the land ownership.
- To put in relation the existing potentialities of the soil and water resource and shapes of affectation of these resources to different scales of needs and intervention.

- To value and to validate the present techniques of conservation of water and soil and struggle against the desertification in the Graguer watershed (Tataouine, Southeast Tunisia).
- To elaborate, in prospective terms, hypotheses on evolutions of resources and the become of the rural populations.
- To elaborate management scenarios while conciliating the global actions (policies of preservation, economic and social priorities, etc.) with local actor strategies.

Description of the Project

The Project Zone Conditions

The zone of survey considered in this project is located in the river basin "Oued Graguer" in Bir Lahmar village (north-west of Tataouine city in the south-east of Tunisia) and incorporates transect from Matmata mountain to Jeffara plain. The choice of this basin is justified for the representative impact of this area, which embodies the overall scenarios in arid zones, within a relatively reduced area.

This region displays the distinctly desert characters and the increasing pressure on its fragile resources with a weak resilience that accentuates the risk of desertification. The morphology of the zone is diversified and several facies of landscapes exist since relief of limestone of the cretaceous of the Matmatas chain until the plains of Jeffara, while passing by piedmont and glazes where predominate lœss and silts easily eroded. The zone of survey is in the Mediterranean climate (wintry rain and dry summer). This climate, arid to Saharan, is characterized by a weak quantity of rain (less than 200 mms) irregular and sporadic (the coefficient of variation is more than 50%) and by a deficit climatic balance for all months of the year. Water resources, relatively limited and in majority no renewable, exist under two shapes: on the one hand, the water of runoff captured by the traditional works to the agricultural means (cultures in jessour) or by modern amenities of water conservation sometimes serving to the refill the underground water table, and on the other hand, the underground waters especially of the Cenomanien water table, integral part of the "complexe terminal".

The traditional production systems combined a concentration of production means on the limited surfaces and the extensive exploitation of pastoral resources in the major zone. During the last forty years, a rapid and a remarkable evolutions of these production systems and natural resource exploitation increased with the underground water exploitation by forages for the extension of irrigated crops and for the industry and a fast extension of arboriculture to transfers the land ownership. In this context, the spatial agrarian system complementarily disappeared and other systems of production interconnected take place. Those systems are marked by a competition for the access to the natural resources and especially for soil possession and water use. A big works of planning and conservation of water and soil on the watershed of the zone have been achieved, whose immediate effects are visible but of which the efficiency on the court and long term was not again clearly valued. These interventions were made by the government by means of big projects that can take with difficulty in account the differentiation of systems occupying spaces.

Project Methodology

In order to realize the target objectives four work packages are identified.

WP 1: Resources: Potentialities, Uses and Impacts of Changes
Operation 1: A start will be made by the characterization of natural resources: water, soils and vegetation resources. The available documents will be compiled, updated and completed.

- With regard to water resources, two types are distinguished: surface and underground waters. For the water surface, the spatio-temporal characterization of precipitations by the analysis of sets of rainfall and hydrometric data (averages, variation, intensity, return periods, runoff coefficients, hydrogrammes, etc.) will be undertaken. Hydro-geologic maps that integrate data related to potentialities, salinity and piezometry will be also elaborated.
- With regard to soils, maps of soil resources and land use will be elaborated. These maps will permit making a first assessment for desertification risk for each geomorphologic zone of the region as well as their agricultural potentialities.

- With regard to pastoral resources, it will be preceded by the identification and localization of the major vegetation units from photo-interpretation and satellites images, and with transect characterization of the major vegetation unit (point-quadrats and biomass strips assessment).

Operation 2: In a second step, it will be preceded by the characterization of resource use systems and the pressure levels on these resources. Analyses will be made on the functioning of the resources use systems. Different scales will be considered according to the nature of resources themselves and the interdependence relations between actors.

Concerning water resources, the preliminary observations show that the numerous soil and water conservation works achieved modified extensively the distribution of this resource from the uphill toward the downstream of basins:

- A big part of the runoff is stopped and is stocked temporarily in the uphill parts (jessour, cisterns); another part is either used for spread unit to underground water recharge. These techniques deprive the downstream parts from large quantities of water necessary to the coastal ecological system balance.
- In the downstream of the basins, the ground water aquifer have been excessively exploitated for irrigation, drinking water (Tataouine, Bir Lahmar), industry and agro-industry.

We propose therefore to analyze these changes in water resource allocation and to study the alternative scenarios for the best management practices taking into account the upstream-downstream relation that will be integrated later in the decision support tools.

Concerning the soil resources, it will be necessary to describe and to analyze the land use systems in relation with the land ownership and their vocations. Impacts of processes of affectation and disaffectation of the land will also be analyzed, as well as those resulting of surfaces controlled by water harvesting management. A particular attention will be given to the survey of the soil fertility because, on the one hand wind and water erosion clean the superficial part of soil reducing so the useful depth and on the other hand the extension of irrigated perimeters using saline water in the zone results in the extension of salt affected areas.

With regard to the pastoral resources, we intend to analyze raising practices in their factual and strategic dimension, within contrasted agro-pastoral systems of the zone (traditional rainfed agriculture of mountain, dominant olive culture with component raising, agro pastoral of plain (cereals - ovine) and herds that graze collective lands including halophytes zones. We propose to characterize the pastoral resource utilization in these systems of production in link with functions assigned to the activity of raising and the other opportunities of fodder productions. The follow-up of exploitations will be put in place: 1) the survey of practices of feeding, reproduction and exploitation herds, 2) the survey of interfacings herds - no cultivated vegetation (vegetation characterization, spatio-temporal animal load and pastoral pressure) and 3) exploitation treasury balances.

Operation 3: On the other hand, in a prospect for assisting in the decision making, two actions of modelling are considered:

- Concerning water resources, we intend, on the basis of hypotheses formulated at the specific objective 4, to elaborate a diagram that reconciles the contradictory objectives of valorization of the resource and struggle against the different shapes of deterioration in the basin. A multi-objective and compromise model using dynamic methods of programming could be elaborated.
- Concerning the pastoral resources, an action of viable trajectory modelling related to agro-pastoral speculations within exploitations will be considered using the theory of the viability. The hypothesis reposes on the idea that in the uncertain environments, the diversification of activities is an efficient way to manage risks.

These activities will be feared in the framework of the various evolution contexts that took place since about thirty years (sedentarisation, privatization of lands, market economy opening, industrial and tourist development).

WP 2: Strategies of Actors in the Context of Competition for Access to Resources

The evolution of natural resource use systems is bound to the social, economic and agricultural transformations that the region has known since the independence. Two periods are to be distinguished:

The period of basic management and equipment of the region (from 1956 to 1970) was characterized by the nomadic populations fixing on the affected lands and the beginning of an agricultural development. It is the coastal fringe of the Jeffara that benefit the maximum of agricultural and tourist infrastructures. In this period, the preservation of resources was not a major concern.

The period of economy liberalization and agricultural enhancement (1970 until now): After the failure of the collectivization politics, the private initiative regained full interest. If the pastoralism decreased strongly, agricultural development was boosted especially with the access to deep hydraulic reserves and the promotion of small hydraulics techniques. This development was not realized without difficulties (conflicts between the big water users: cities, tourism, agriculture - competition for the land appropriation - unbalance between the upstream and the downstream of the zone, etc.;

This evolution drives the government to be today a mediator preoccupied in the same time by the resources preservation and the regional development. In this study, it is indispensable to know the different actor strategies at different scales of intervention (local, regional, national) and the capacity of actions put in place to play a mediating role between these different actors (from the agricultural operator to the state passing by the intermediate levels of intervention) for conflicts settlement and in the resorption of practices responsible for the desertification and the rarefaction of resources.

The method will be based on the new approach of institutional economy and socio-anthropology methods by identification and mobilization of key actor and by the definition of long-term management objectives.

Some operation will be therefore realized:

Operation 1: inventory of the state services and the different organisms working in the region (NGO, Associations, AIC)

Operation 2: diagnosis on the organization level of the region integrating the socio-economic conditions of the region (in particular all those that are in link with the soil and water utilization) and the geophysical conditions.

Operation 3: an investigation will be undertaken nearby the institutional actors and the private actors in order to identify the relation between the committed actions and the future projects according to the local strategies.

WP 3: Rural populations adaptations in terms of answer to environmental changes: production systems, domestic strategies, land ownership systems and income of users population

This work package reposes on two hypotheses:

Hypothesis 1: changes imply new households strategies mainly:

- the increase or the reduction of the domestic cell (household, family) that refers to all attributes of life (education, habitat, health, patrimony) and to the income that it is necessary to possess them (this depends on economic conditions at that moment)
- the rarefaction or the abundance of a resource (or resources) that refers to the viability of production systems

Hypothesis 2: there is not necessarily adequacy between an answer and a type of change, but there is an interconnected complex system of strategies. These can be divided into two types:

- The socio-economic strategies that concern the composition of the household (size, domestic cohabitation, etc.), the domestic scattering (migration) and the domestic labour manpower (pluri-activity, etc.);
- The productive strategies that concern production systems and factors that underlie them: the land appropriation (land ownership), state of resources (soils, water, vegetation cover), affectation of productions (autosubsistance, marketing, etc.)

To analyze these different elements, the experienced methodology in the DYPEN "population Dynamics and environment " program will be used. It will proceed to put in place a system of collection data at the regional and local scales under the shape of GIS containing

at the regional level:

- an ecological zoning including the land occupations,
- a map of the land ownership,
- an administrative map including the habitat and the infrastructure,
- an investigation with three components: socio-demographic, agricultural operating systems, natural resource use,

at the local level:

observatories focused on a specific socio-environmental problematic (water management, oasian systems, arboriculture)

The problem of the observation will probably be to take in account the diversity of the zone while distinguishing the relatively homogeneous zones as for their operating systems of the uphill to the downstream of the basin. This classification may not be applicable in zones with multi-vocation. It goes also in the same way with population structures that cannot be in agreement with the agricultural zoning. It is important so to choice the indicators or typologies able to be spatialised and that could illustrate the different factor weight (often specific to a zone, for example the problem of the water management) in the evolution processes. In the same way, it will be necessary to identify the social groups susceptible of an adaptation to economic-environmental conditions, distinguished of those who risk to emigrate.

The most prominent steps of this work package are:

Operation 1: Population evolution since the independence from the statistical sources of the INS (National Statistical Institution – Tunisia)

Operation 2: An investigation close to the agricultural operators on the domestic structures, the activity in the household, production systems, fashions of water management,

<u>*Operation 3:*</u> A survey of the land ownership and systems of appropriation of the land,

<u>*Operation 4:*</u> Development of a data base figures and indicators

WP 4: Assessment and validation of the present techniques of combating desertification

Basic hypothesis: In a context of over utilization of resource particularly soil and water resource, the traditional and modern technique juxtaposition was not studied in detailed in order to value their efficiency. Indeed, this juxtaposition could be one of reasons of an unbalance of the resource allowance in water, can drag a surplus or a deficit according to zones and can constitute homes of localized desertification.

An exhaustive inventory of these techniques will be achieved following an interdisciplinary and participative approach. An assessment of techniques will be realized taking in account uses and the technical and socio-economic problems (design of water harvesting construction problems, elevated cost, acceptability by populations, etc.). This process should lead to validate some of these techniques, to raise their failings and to propose measures to take to improve or to replace them. The idea here is to create a consensus between the different actors (technicians, populations, researchers, decision-makers) on techniques of water harvesting and struggle against the desertification, which regroups at a time technical efficiency, acceptability for population's users and socio-economic profitability.

The historic traditional technique profiles will be achieved (diachronic analysis). We will study how the modern techniques came in complement, in replacement or in conflict with these techniques, so that results and hypotheses of descended assessment of this theme are integrated to the global hypotheses of evolution and tools for help to the decision makers.

In summary, three operations will be achieved:

<u>*Operation 1:*</u> Inventory and description of the different techniques used in the region using technical data of the regional department of

agriculture (CRDA) and investigations and prospecting to be undertaken on the zone.

Operation 2: participative and interdisciplinary assessment of the different techniques using specific investigations to each technique. It will be proceeded by activate methods for participatory research (MARP), (historic profiles, transects, etc.) for focus group.

Operation 3: It will finally to proceed to provide a convenient manual that raises the inventory, the technical description (processes, etc.) the social and economic interest, the degree of acceptability by the population and the possible improvement propositions (according to an approach participative) of the different techniques of struggle.

Justification of the Project

Literature and state of knowledge

Several works realized by IRA and by other intervening institutions produced an important knowledge and results in the field of combating desertification and water and soil conservation :

- Socio-economic assessment of agro-sylvo-pastoral works in arid and desert zones: several researches and studies of assessment of agro-sylvo-pastoral experiences have been realized. we can mention, for example, the assessment of the project of Oglet Mertba and the project of combating desertification of Menzel Habib (Abaab, Sghaier, Laamari, Abbots 1994; 1993; 1988).
- Identification and analysis of the agro-sylvo-pastoral production systems in arid zones of Tunisia mainly in the Jeffara: the application of the systemic approach touched several types of agriculture of the center and south Tunisian notably, the pluvial and irrigated agriculture in Sidi Bouzid (in collaboration with the ASDI (Sweden) and the CRDA of Sidi Bouzid), the continental (Kébili) and the coastal (Gabès) oases and steppic agriculture and raising in the agro-pastoral zones of the Tunisian Jeffara (Abaab, Sghaier, Nasr, 1997,; 1995; 1994; 1993; 1991; 1988).
- Survey of the agrarian systems and the spatial organization in the Tunisian southeast; this work permitted to measure

the mutation impacts of production systems and the government politics on the management of the space and the natural resources. Thus, a comparison between systems of production based on irrigation and those based on the agro-pastoral activities have been made and permitted to demonstrate the agro-pastoral system durability in extensive based on the complementary extra-agricultural incomes (Abaab, Nasr, 1993,; 1991).

- The identification of techniques for dune fixation in olive trees plantation, the improvement of the efficiency of inert wind break and combating the wind erosion in the plowed lands (Khatteli, 1988, 1997).
- The identification of the most degrading soil plowing tools (polydisc plow) (Khatteli and Kardous, 1997, 1998).
- The cartography of the landscape dynamics of and the land use on several zones of the Tunisian south notably the Jeffara in the aim to elaborate an integrated system of information on the environment for help to the decision (Talbi, 1993).
- Setting up of a participatory and interdisciplinary approach of research-development in agro-pastoral zone of the Jeffara in collaboration with the regional department of agriculture, international institutions and the population (regional research projects, CRDI, Alger university, IAV Hassen II Morocco, etc.).
- Setting up a research-development test concerning natural resource management in arid zones (regional project IRA/ICARDA and 5 institutions from WANA). This test is led according to an interdisciplinary approach associating population and regional department of agriculture (Sghaier, Nasr, 1993).

Justification of the Methodology

In the context of transformations of production systems and their diversification dragging an over utilization of resources and public power interventions to stop desertification processes without burdening the region development. It is important to review the desertification problem in an alternative problematic that takes in account the complex and various forms of population environment relations. It is also important to consider that the man's impact on resources has not always a degrading characters. This requires a multidisciplinary approach to distinguish among factors of evolution those that have an anthropic origin of those that have climatic or physical reasons and to identify interactions between these different factors.

The setting up of control techniques taking account of the human milieu and the natural resource state implies the recourse to analysis instruments that take in account all disciplines. The choice of indicators is essential to judge the efficiency of actions and to appreciate tendencies of deterioration. The experience acquired by the research teams of DYPEN " population Dynamics and environment ", CAMELEO program " Long term change observatory in the arid Mediterranean ecosystems" and the CSFD (Caisse Scientifique Française pour la Désertification) project in the Zess-Koutine (South-east of Tunisia) will be considered to achieve the proposed project. These teams acquired in common a considerable mass of data on the physical and human in the Tunisian arid zone. From these data, bases of knowledge and methodologies of analysis and modelling on the co-evolution of the different ecosystem behaviours have been built; the social changes that modify modes of resources exploitation and the access to the resources have been analysed and have been served to choice actions for the development of these zones.

Finally, the intervention of different organism cannot have a real efficiency without a strong knowledge integrating human and ecological factors. The major justification of this project is to provide some guidelines to the future actions, to place these actions in a long-term perspective where hypotheses of resource evolution and societies can be interpenetrated.

Innovative Aspects of the Project

- A methodology already based on techniques tried in other programs, permitting to connect the different evolutions (DYPEN program or CAMELEO etc.): interfacing adjustments, modelling, population and ecological data spatialisation, etc.
- Analyses on interactions between population and natural resources from already realized works on the region.

- An assessment of the efficiency of techniques of management and rehabilitation of the milieu not only by their technical performances but also by their capacities:
  a. to fit to the evolution of actor practices (valorisation, appropriation),
  b. to regulate the competition of access to resources,
  c. to reorient choices concerning the most underprivileged sectors,
  d. to permit choices of management policies.

Link with the Tunisian Politics

For the past two decades, the Tunisian government has initiated a vast program of preservation and mobilization of resources: the national program for combating desertification, the national program of Water and Soil Conservation, the plant and forest resources protection (Forest Code), etc. Using the available international and national funds, the government achieved some considerable actions for wind and water erosion control, fruit and cereal species selection, controlled the chemical entrants introduction, etc. All the agricultural landscape of the country have been concerned. The social measures (education, health, etc.) and economic (organization of markets, struggle against unemployment) accompanied this large movement of developing the Tunisian farming milieu; the underprivileged zones have been electrified, opened by the construction of roads and trails, the use of gas for the domestic energy has been spilled decreasing the pressure on the forest and woody resources everywhere. All these measures touched the region of the Jeffara. They were factors of the societies and the agrarian systems transformations but dragged other shapes of pressures. The proposed survey put the accent thus on the social and productive answers that populations adopted facing all these changes at the collective level (institutional actor strategies, traditional groups, etc.), and at the households level (familial strategies). These analyses should permit to take hold of the impact of development policies decided at the national level, their efficiency according to the capacity of populations, to accept them and to take advantages.

Scientific and Socio-Economic Benefits

- To develop a suitable methodology for the assessment of planning techniques and the public power interventions,
- To provide tools of help to the decision, of piloting of interventions and assessment,
- To put an operational system of desertification monitoring on the natural resource through the development of an ecological plan of long-term control aiming to evaluate the ecological and socio-economic factor impacts on the dynamics of the milieu.

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Summary Report of the Workshop

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Summary Report of the Field Trip

Day 1: Monday – 6 November, 2000

08:30-11:00	Travel from Damascus to Mehasseh
11:00-13:30	Visit to Mehasseh Research Station
13:30-15:00	Travel to Palmyra
15:00-16:00	Lunch & check-in at Cham Hotel (Palmyra)
16:30-18:30	Tour in Palmyra
19:00-20:30	Dinner Reception

Travel from Damascus to Mehasseh

There is a rocky landscape with a very thin soil cover and a steppic vegetation cover (called Badia or Wadia in Arabic) between Damascus and Mehasseh. Generally, the land resources are quite degraded in part due to overgrazing and three consecutive drought years. The steppe region occupies 55 to 66% of the land in Syria where rainfall is less than 200 mm/year. This area is grazed from November to March (the rainy season) by the herds of the Bedouin (Syria has some 350,000 Bedouins); sometimes they are joined by Bedouins from Iraq. They typically return to the north during the dry season from April to October, where they graze the stubble of the agricultural land. The distance traveled by the Bedouin is about 200 km per year on the average. Importantly, there is no private ownership of the land which has consequences for natural resources management.

Visit to Mehasseh Research Center for the Development of Natural Agricultural Resources in the Syrian Steppe

The Mehasseh Research Centre is located about 120 km northeast of Damascus at an altitude of 800-950m (34°08 N and 37°2 E). It has a hot and dry summer, scarce rainfall (114 mm/yr) and an average annual evaporation of 1750 mm. During the last two years, this area has suffered a severe drought with annual rainfall under 35 mm/yr and a runoff of 0 to 27 %. The soil in this area is loamy with medium storage capacity and negligible organic matter. The area has historically suffered from overgrazing. Therefore, water harvesting is crucial to increase the intensity of grass and shrub cover.

The main objectives of the Research Centre are :

- to improve surface and groundwater use efficiency,

- to protect soil, water and vegetation resources from deterioration by wind erosion, water erosion and chemical degradation,
- to develop and manage the natural resources (soil, water, plant cover),
- to improve the production efficiency of sheep,
- to study the economical and technical feasibility of water harvesting and spreading techniques, and
- to revegetate so as to make the land available for the Bedouins.

The facilities at the Mehasseh Research Center include:

- an analytical laboratory,
- a meteorological station and rainfall observation units,
- a water collection dam – 600 m long and with 300,000 m3 capacity,
- seven groundwater wells, including a pump,
- five runoff water harvesting reservoirs of 2,050 to 2,900 m3 each,
- drip and sprinkler systems for selected areas with olive trees and crops, and
- test plots for measuring erosion and runoff.

There two major projects at the Mehasseh Research Centre:
Project 1: Integrated watershed development project in the Syrian steppe in collaboration with the International Development Research Centre (IDRC) and the United Nations Development Programme (UNDP). This project seeks to develop a model for the sustainable development of arid lands watersheds through the integrated management of their water, soil and vegetation resources. This will help improve the utilization of steppe's resources and ensure a sustainable animal production. As a part of the research work, the impacts and cost/benefit of various alternatives on water conservation, erosion control and revegetation at the watershed level are evaluated on a long-term basis. Rainfall water is harvested through strip contouring, which provides sufficient water for animal consumption.

Project 2: Optimum water use at farm level through On-Farm Water Husbandry in WANA in collaboration with ICARDA. The main objectives of this second project is to find out practical and effective methods of water harvesting for planting shrubs on the slopes by reducing runoff and controlling erosion. The project utilizes techniques that increase the continued local exploitation of rainwater and prevent the degradation of natural resources. Several micro-catchments are evaluated for water harvesting by economic methods that cause no erosion. These include an experiment based on runoff improvement catchments that are natural, paved, planted or plastic-covered. Micro-catchment bunds are developed manually as semi-circle curves 2 to 6 m in length.

Visit to Palmyra

Palmyra ("the place of Palms") is about 250 km northeast of Damascus and is situated at an oasis in the desert. This ruined city is at a considerable distance from any rivers (150 km from the Orontes river in the west and 200 km from the Euphrates in the east). Palmyra's local name is Tadmor and it has been a settlement since Neolithic times. From about 1000 B.C. for about one millennium it was an Assyrian caravan town and later became an important outpost of the Greek Empire for about two hundred years. The city's most famous ruler was the warrior Queen Zenobia (266 A.D.), said to be a descendant of the Egyptian Queen Cleopatra. In 217 A.D. it was annexed by Rome and enjoyed a period of astonishing wealth, gained from taxation on the flourishing caravan trade. In 634 A.D. the city was conquered by the Muslims and in 1089 A.D. was totally destroyed by an earthquake. The ruins at Palmyra include the temple of Del, the Agora (theatre) and an ancient market with 11 doors. Additionally, a rich necropolis was excavated a few years ago by Japanese experts in collaboration with a Syrian team.

Day 2: Tuesday – 7 November, 2000

08:30-10:00	Travel from Palmyra to El-Sukhnah
10:00-11:00	Visit to qanat site and oasis at Taibeh
11:00-13:00	Travel from El-Sukhnah to Deir Elzor
13:00-14:00	Lunch & check-in at Euphrates Cham Hotel (Deir Elzor)
14:30-16:30	Visit to Irrigation Scheme in Deir Elzor

Visit to the Oasis of El Sukhnah

Although of small size, the oasis of El Sukhnah (34°56 N and 38°52 E) meaning "hot place." This area served the Bedouin tribes grazing between Arabia and Syria up to the 19th century. This oasis was also a stop for the caravans of pilgrims to Mecca. There are a few farmer families, but the pride of the majority is trading. Its importance declined since the 1940s with the advent of motorized transport. However, there has been a revival of traffic since 1982 when the highway connecting Damascus-Palmyra-Deir Elzor was opened. In spite of the disappearance of its function as a caravan stop, El Sukhnah is revived in a new capacity due to its filling stations, restaurants and its numerous artisans (welders, blacksmiths, and auto-mechanics). In addition to its commercial function, intensive sheep production here, as in the whole Palmyrene region, was responsible for severe land degradation.

Visit to the Qanat system and Oasis of Taibeh

This area has been investigated since 1967 by Professor Iwao Kobori. In 1967, the oasis had 300 inhabitants; now its population is between 1,000 and 2,000. The oasis had a traditional system of qanats, nowadays abandoned and replaced by a water pumping system operating at a 10-m depth. The poor quality of water in the open drains was apparent due to influx of wastes from the village. Also, because the drains are open, the losses due to evaporation are relatively higher, when compared to an enclosed qanat system.

During the visit of the oasis plantation, we saw the farmers taking out weeds and their roots to decrease potential evapotranspiration. These farmers employ an interesting traditional technique that consists of an inverted conical accumulation of loose soil around the foot of the trunk of the olive trees. This technique has four objectives: to protect the stem of the tree from the direct contact of irrigation water, to bring nutrients through a natural manure, to increase the water retention capacity around the trunk and to provide support to the trunk.

Agriculture is not allowed in the Syrian steppe. Therefore, each tribe receives from the government a territory for grazing. The breeding is organized by the system of hima, where theoretically the herders have no more animal that the carrying capacity of the land. Nevertheless, the government provides subsidies to the farmers in the form of a supplement of wheat and other cereals. This, in turn, leads the farmers to increase their herds resulting in endemic overgrazing.

Visit to the Gold 7 April Farm

These farms are maintained by the Ministry of Irrigation at a location about 20 km from Deir Elzor and 120 km ESE of Aleppo. The 250,000 hectares of this farm are equipped by an irrigation system and a vertical drainage system based on a set of wells 30 to 50m deep. There is an interesting pumping system that pumps automatically when the underground water, as a result of waterlogging, reaches a depth of 4m and then it stops automatically when groundwater table falls down to 5m. This system favors infiltration and leaching of excess salinity. The soil in this area has a loamy texture and is rich in gypsum and sodium chlorides. This requires the canals to be elevated above the ground to avoid deterioration of the concrete through chemical action. In spite of the good drainage system, some salinized fields have to be abandoned because desalinisation is deemed too expensive.

The main canal is 15 km long with a flow of 15 m3/s; the secondary canals are 450 km long. The irrigation water comes from the Euphrates river and the waste waters are reverted back to the same river. This farm cultivates specially cotton of high quality, cereals (wheat, maize), and sunflower. The irrigation systems used include pivoted sprinklers and drip irrigation. The pivoted sprinklers can be problematic because of the high cost of energy consumption; the losses by evaporation may be from 7 to 20%.

Day 3: Wednesday – 8 November 2000

08:30-10:30	Travel from Deir Elzor to El-Thawra (Al-Raqqa Province)
10:30-11:00	Visit to irrigated areas from Lake Assad
11:00-13:30	Visit to Euphrates Dam
14:30-15:30	Lunch in Tabaqua
15:30-17:00	Travel from El-Thawra City to Aleppo

Farm Area between Deir Elzor and Al-Raqqa

From Deir Elzor we take the road to Raqqa along the Euphrates Valley at the foot of magnificent terraces of the right bank. The whole plain is used by supplemental irrigation with some adverse impacts (partial salinization) due to high gypsum levels in the soils. The stubbles in the cotton fields are use in this season as forage by the sheep and in winter as source of energy. Maize fields and sunflowers are alternated, with plantations of poplar, eucalyptus and olive trees.

Irrigation Scheme of Beer El Hashrem

The irrigation scheme of Beer El Hashrem is located on the left bank of the Euphrates river in direction of El Thawra. The project Beer El Hashrem is a farm built by the government and will be handed over to the farmers. This 10,000 ha project is irrigated by basin irrigation without drip irrigation or sprinklers. Three pumping stations bring the water from the Euphrates river. The farmers pay for the water according to the surface cultivated at a rate of approximately US$ 50/ha/year. It is estimated that the price of water will recover the capital cost of the project in 25 years.

The rainfall is here of 200 mm/yr and therefore less water is needed for irrigation in winter. The main canal was begun in 1993 its flow is 180 m3/s, it receives the water from the Lake Assad. The water requirements for irrigation and drainages are: 14,000 m3/ha/yr for the cotton, 7,000 m3/ha/yr for sugar beans, 6,000 m3/ha/yr for wheat and 3,000 m3/ha/yr for barley. A salt tolerant, wild variety of reeds grow the drainage canals, causing disruption in water flow. Regular and expensive dredging is required to maintain the canals.

Visit to Euphrates Dam at Al Tabaqua and Power Generation Unit

The Euphrates dam project is considered to be the backbone of all economic and social development in Syria. It has a length of 4.5 km, the width of the dam is 512 m at the base and 19 m at the crest; its height is about 60 m. The dam was designed with the assistance of the former Soviet Union. The building began in 1968 and was completed by 1978. The cost of the dam was US$ 340 million, of which US$100 million was lent by former Soviet Union. The main canal is dug in an ancient bed of the Euphrates river and was completed in 1973. The hydroelectric station that constitutes a part of the dam lies on the right bank and is combined with the spillway equipped with eight generating units. The capacity of each unit is 110 Megawatt. The dam has been designed to achieve the following objectives:

- irrigation of a large fertile region, ca. 640,000 ha.,
- electricity production with 8 units of a capacity of 880 Megawatt, and
- regulating and controlling the river's flow.

Two other dams which we did not visit are: Al-Baath Dam and Tishereen Dam. The Al-Baath Dam is already built on the Euphrates river about 27 km upstream from Euphrates Dam, between Al-Thawra and Al-Raqqa towns. The Al-Baath Dam is used for regulating the flow through Al-Thawra hydro-electric station and ensuring the permanent normal head water level of the Euphrates River. This dam has the annual electric power capacity of about 375 million kilowatts. This dam also helps in preserving the fish resources of the river. The second, Tishereen Dam, is under construction downstream on the Euphrates 125 km east of Aleppo, which aims at increasing the electrical power to about 1,600 Megawatts yearly.

Summary of the Technical Sessions

Technical Session 1 - Critical Issues of Water Management in Central Asia (Chaired by Prof. Motoyuki Suzuki)
This session was designed to provide a broad overview of the water management issues in Central Asia – an important step in setting up the stage for more in-depth discussions. The historical background of the water management paradigm in the region was explored and discussed. The potential solutions to existing problems were discussed and highlighted.

The key discussion points for this session may be summarized as:

- The problems related to water resource management in Central Asia are complex and are intertwined with social, economic, political and technical issues. Because the region is naturally land-bound, options available are somewhat limited. Major problems include quantity of water available, pollution of available water, salinization of soils, and land degradation.
- At is important to view water resources strategically at the river basin level. This has to be done with full realization of the changed geopolitical scenario in the aftermath of the breakup of the former Soviet Union. This has particular implications for any water transfer in and between river basins, particularly when such transfer schemes would cross national boundaries.
- The issues of water availability are closely linked to human welfare and health as well as food and economic security. It is therefore essential that teams working on water resource management should be multidisciplinary and they must work in close consultation with local communities.
- Appropriate management and maintenance of existing irrigation systems is critical for long-term sustainability. It is equally important to consider demand management of water resources (rather than supply management only).
- Development of any infrastructure in the future for water management should be carefully evaluated for its impacts on the environment.

Technical Session 2 - Approaches for Management of Water Resources (Chaired by Prof. Iwao Kobori and Prof. Ahang Kowsar)
This session was designed to provide an overview of water management approaches currently employed in the region. Water resource management practices in Uzbekistan, Kyrgyzstan, Tajikistan, and Pakistan were discussed.

The key discussion points for this session are:

- The existing water management systems are often complex, with limited capacity for adoption of advanced technologies. Limitation of fiscal and human resources often drive the adequateness of the management practices. The number of water users has increased dramatically as communal farming systems give way to individual farmers; this is further exacerbated due to a rapidly-increasing population in the region.
- The bureaucratic mechanisms in place to oversee water management are also complex at the national level; these have to cope with the transition to a market economy. The international water management mechanisms are in their infancy at the time and are undergoing evolution.
- The currently functional water distribution systems often result in uneven distribution of water between end-users. Poor drainage systems lead to salinization of soils.
- Integrated water management approaches, that account for all natural resources, with full involvement of local communities have been successful. Another successful approach is to promote landscape architecture and move away from traditional, mono-cropping agricultural systems.
- Governments sometimes provide perverse subsidies to projects that are over-utilize the existing water resources and are detrimental to the environment in general.

Technical Session 3 - Innovative Solutions, Including Wastewater Reuse (Chaired by Dr. M. Sulemeinov and Prof. Genady Golubev)

A number of innovative approaches and solutions to water resource management were discussed in this session. Particular emphasis was given to the notion of utilization of so-called wastewaters for agricultural uses. Some examples of such wastewater re-use were discussed.

The key discussion points for this session are:

- The chronic shortage of water in arid areas requires us to look for new and innovative solutions. One key element is to recycle and re-use as much of the water available as possible. This, obviously, requires development and implementation of wastewater treatment technologies as well as effective management of existing resources.
- Effective management and maximizing productivity of existing water resources is critical in dry areas where water harvesting and supplemental irrigation can be useful. It is also important to keep in mind that often optimum crop production can be achieved by spreading supplemental irrigation over larger tracts of land. In other words, water – and not land – is the limiting factor in enhancing crop productivity.
- For wastewater treatment technologies to be effective, they have to be relatively inexpensive and amenable to local production. In this respect, due attention should be given to natural ecosystems as treatment processes, such as soil infiltration treatment and oxidation ponds.
- The long-term impacts of applying treated wastewater should be carefully evaluated. Particularly, the long-term impact of heavy metals and other pathogenic pollutants commonly found in wastewaters should be assessed. The impacts on both environment and human health deserve our attention.
- Sustained monitoring is necessary in areas where treated waters are applied. This monitoring can be further enhanced through modeling and simulations.

Technical Session 4 - Case Studies

(Chaired by Prof. Monique Mainguet and Dr. S. Beniwal)

A number of case studies were presented in this session; including those from Kazakhstan, Kyrgyzstan and China. An overall agroclimatic characterization of Central Asia was also described.

The key discussion points for this session are:

- A regional overview of the agricultural and climatic conditions can be helpful in improved and targeted production of crops. Such evaluation is also help in prioritizing activities to combat land degradation.
- At a regional scale, the mono-cropping systems are slowly and gradually giving way to multi-cropping systems. For Central Asia, this approach reverts back to more traditional farming practices where many cereal crops were grown, leading to increased food diversity and security.
- The highland-lowland interactions play an important role in management of water and natural resources. This is particularly important for mountainous regions in Central Asia, China and Pakistan.
- Given the transboundary nature of resource management problems, it is advisable to develop regional solutions. This, in turn, requires formulation of institutions and organizations capable of handling problems at a regional scale. Needless to say, this requires regional cooperation at social, technical and political levels.

Discussion Session - Country Proposals and Workshop Recommendations (Chaired by Dr. Theib Oweis and Dr. Zafar Adeel)

The main objectives of this session were to discuss the critical issues for water management and formulate recommendations for future action. A broad range of issues were prioritized in accordance with their regional importance, giving due consideration to the fact that priorities for natural resource management vary from region to region. The UNU programme was presented in this session along with proposals from Iran, Niger and Central Asia. The recommendations of the workshop can be summarized as follows:

Critical Issues

The critical issues for water and natural resource problems are summarized here:

- In the dry areas discussed during the workshop, there is a deterioration of natural resources, including water, biodiversity, soils (various causes such as salinization, wind erosion etc).
- The problems and issues related to natural resource management and conservation are often complex and interrelated. This requires a multidisciplinary approach to solving these problem.
- The problems occur at a variety of scales, ranging from international to local. Appropriately, the solutions must also be implemented at the respective scale. Such solutions should give due attention to upstream-downstream and highland-lowland interactions.
- The dry areas in the focus of this workshop suffer from harsh climatological conditions. Most importantly, there is a severe water scarcity that is getting worse due to rapidly-increasing population.
- In general, there is a lack of capacity to adopt more sophisticated options. This obviates two types of actions. Firstly, the solutions developed should be appropriate for adoption and utilization in developed countries. Secondly, new initiatives to build the institutional, infrastructure and human capacity should be undertaken.
- The governments have a critical role to play in natural resource management. This particularly manifests itself in

the form of subsidies, over-/under-exploitation of natural resources, and infrastructure for management of water resources. Pricing of water resources is another important element that has ramifications for financial resources available for infrastructure development as well as utilization/wastage of available water.

Priorities Issues in Central Asia

- Improvement and enhancement in water use efficiency and water productivity are critical. This can be achieved by adopting appropriate management practices. Water harvesting can play a key role in this respect.
- Salinization of soils is a critical issue and it impacts the land productivity. Existing water distribution systems and their inappropriate maintenance are partly responsible for a deteriorating situation. Water and wind erosion of soils is also an important issue.
- Due importance should be given to traditional and cultural practices utilized in agriculture and water resource management
- Proper rangeland management is crucial to avoid over-grazing and subsequent land degradation.
- The marginal areas in Central Asia have scarce availability of both water and energy. This indicates the need for capacity building and infrastructure development. Similarly, the human resources, such as scientists and technicians, have to be developed through an increased investment.
- Particular importance has to be given to information management and dissemination in this region.

Priorities Issues for West Asia and North Africa

- Increasing water productivity is critical – again water harvesting has an important role to play in this respect.
- The areas suffering the most are marginal areas, those lying at the periphery of productive lands and desertified areas. These marginal areas suffer from worst land degradation and lead to poverty and misery for the people depending on this land.

- Information dissemination is also a problem, but the situation is gradually improving. Development of networks at professional and societal level can help alleviate this problem.
- An effort has to be made to transfer the technologies from other regions suffering similar problems and adapt them to local conditions.
- In general, the quality of water available in this region is not good. Problems with high level of minerals as well as anthropogenic pollution impacts are attributable.

Approaches for Water Management

A number of approaches for water management are available. Some of the key elements for these approaches were discussed in this session:

- The water management approaches have to be multidisciplinary, multi-stakeholder. It is most important involve end-users, such as farmers, in development and implementation of activities.
- Scientifically-based policy guidelines should be developed for governments. The long- and short-term evaluation of environmental and socio-economic impacts of such policies should be a critical component of the policy development process. Also important is to consider demand management policies, rather than focus just on water supply side.
- Governments as well as communities should make efforts to maintain and improve existing facilities and infrastructure for water management.
- To maximize the water productivity, it is essential to improve and achieve a more targeted production of crops.
- The traditional practices have been developed over centuries and are often best-suited to local conditions. However, due consideration should also be given to enhancement of indigenous and traditional management approaches, wherever applicable.
- A key element of successful water and resource management is building partnerships for joint action. These partnerships can be at the institutional or professional level; the scale can vary from local to international.

New and Innovative Approaches to Water Management

Several new and innovative approaches are available for water management; although their application requires caution and careful evaluation. Some of the key approaches discussed during the workshop are:

- Water productivity can be significantly improved through recently-developed approaches of water harvesting, supplemental irrigation and deficit irrigation. These technologies have been quite successfully tested at pilot scale and now require a broader implementation.
- A number of approaches are available for safe and productive use of recycled water in agricultural applications. Again, these have been evaluated at relatively small scale and require a more careful evaluation as broader-scale implementation schemes are developed.
- In conjunctions with recycled water application, emphasis has to be given to development of cheaper water treatment technologies that are suited to local conditions.

Workshop Programme

Sunday, November 5:

Arrival of participants in Damascus

Monday, November 6:

08:30-11:00	Travel from Damascus to Mehasseh
11:00-13:30	Visit to Mehasseh Research Station
13:30-15:00	Travel to Palmyra
15:00-16:00	Lunch
16:30-18:30	Tour in Palmyra
19:00-20:30	Dinner Reception

Tuesday, November 7:

08:30-10:00	Travel from Palmyra to El-Sukhnah
10:00-11:00	Visit to qanat site and oasis at Taibeh
11:00-13:00	Travel from El-Sukhnah to Deir Elzor
13:00-14:00	Lunch (Deir Elzor)
14:30-16:30	Visit to Irrigation Scheme in Deir Elzor

Wednesday, November 8:

08:30-10:30	Travel from Deir Elzor to El-Thawra (Al-Raqqa Province)
10:30-11:00	Visit to irrigated areas from Lake Assad
11:00-13:30	Visit to Euphrates Dam
14:30-15:30	Lunch in Tabaqua
15:30-17:00	Travel from El-Thawra City to Aleppo

Thursday, November 9:

08:00-09:00	Registration
09:00-10:00	Opening Ceremony
10:00-10:30	Coffee break

Technical Session 1 - Critical Issues of Water Management in Central Asia
Chaired by: Prof. Motoyuki Suzuki

10:30-11:00	Systems view at the water management in Central Asia (Golubev)

11:00-11:30	Water problems in Central Asia - Gigantomania should be replaced by small projects (Mainguet)
13:30-12:00	Central Asian studies in our research perspective – A personal view (Kobori)
12:00-12:30	On-farm soil and water management for sustainable agricultural systems in Central Asia (Karajeh)
12:30-13:00	Discussion on Session 1
13:00-14:30	Lunch

Technical Session 2 – Approaches for Management of Water Resources

Chaired by: Prof. Iwao Kobori and Prof. Ahang Kowsar

14:30-15:00	Water management in Uzbekistan (Djalalov)
15:00-15:30	Present water resources management system in Kyrgyzstan (Atakanov)
15:30-16:00	Coffee break

Friday, November 10:

Technical Session 2 – Approaches for Management of Water Resources (continued from 9 November)

Chaired by: Prof. Iwao Kobori and Prof. Ahang Kowsar

08:30-09:30	Tour of ICARDA Facilities
09:30-10:00	Soil and water resources in the agricultural sector of Tadjikistan (Sanginov)
10:00-10:30	Community participation and water management in Balochistan, Pakistan (Nawaz)
10:30-11:00	Coffee break

Technical Session 3- Innovative Solutions, Including Wastewater Reuse

Chaired by: Dr. Mekhlis Sulemeinov and Prof. Genady Golubev

11:00-11:30	Energy-efficient water treatment technologies (Suzuki)
11:30-12:00	Management of scarce water resources in agriculture (Oweis)
12:00-12:30	Use of purified wastewaters of Almaty for the irrigation of feed crops (Petrunin)
12:30-13:00	Discussion on Session 3
13:00-14:00	Lunch

Technical Session 4 – Case Studies

Chaired by: Prof. Monique Mainguet and Dr. S. Beniwal

14:00-14:20	Agroecological characterization of Central Asia (De Pauw)
14:20-14:40	The use of domestic and industrial recycled water in Kazakhstan (Karajeh)
14:40-15:00	Case study of work in Arys-Turkestan, in Southern Kazakhstan (Mukhamedjanov)
15:00-15:30	Coffee Break
15:30-16:00	Irrigated agriculture and sustainable water management in Tarim river (Hongfei)
16:00-16:30	Case study of water management in Kyrgyzstan (Akimaliev)
17:00-17:30	Discussion on Session 4

Saturday, November 11:

Discussion Session 1 – Presentation of Country Proposals

Chaired by: Prof. Motoyuki Suzuki and Prof. Adel El-Beltagy

08:30-09:00	UNU Programme - Integrating land management in dry areas (Adeel)
09:00-09:30	Proposal - Floodwater for irrigation and groundwater recharge (Kowsar)
09:30-10:00	Proposal - Combating land degradation in Central Asia (Nasyrov)
10:00-10:30	Proposal - Participative research on land management in desert margins (Dieudonne)
10:30-11:00	Coffee Break

Discussion Session 2 – Workshop Report Development

Chaired by: Dr. Theib Oweis and Dr. Zafar Adeel

11:00-12:00	Presentation of Draft Workshop Report (Oweis & Adeel) Open Discussion
12:00-12:30	Development of Workshop Recommendations
12:30-13:00	Closing Ceremony
13:00-14:30	Lunch

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UNU Desertification Series No. 3

NEW APPROACHES TO WATER MANAGEMENT IN CENTRAL ASIA

Edited By Zafar Adeel

Proceedings of
A Joint UNU-ICARDA International Workshop
held in Aleppo, Syria
6-11 November 2000

This workshop, jointly organized by UNU and ICARDA, primarily focused on the challenges in water management faced in the Central Asian region and explored new strategies to cope with them. The papers in this volume focus on water management within the broader theme of approaches for integrated land management.

A number of promising approaches for water management are discussed both in Central Asia and in other locations. These include rainwater harvesting techniques, aquifer recharge methods, and applications involving re-use of municipal sewage or wastewater. In conjunction with recycled water application, development of cheaper water treatment technologies suited to local conditions is also described as a recommended approach.

In general, water productivity can be significantly improved through these recently-developed approaches and in some situations very significant benefits can be reaped through enhancement of indigenous and traditional management approaches.

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