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INTEGRATED LAND MANAGEMENT IN DRY AREAS

Proceedings of
A Joint UNU-CAS
International Workshop
held in Beijing, China
8-13 September 2001

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Edited by
Zafar Adeel

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Preface

The dry areas of the world, including arid, semi-arid and dry sub-humid regions, suffer from adverse climatic and natural conditions. The over-utilization of natural resources, particularly water, in these dry areas leads to major stresses on the ecosystem. This effect is multiplied by rapidly increasing population. The problems faced in dry areas are indeed complex. There is an increasing awareness that the natural resources in dry areas must be managed in an integrated fashion. These management approaches must be implemented in close cooperation with local communities and end-users.

This workshop was quite productive in highlighting the stresses faced in dry areas and integrated land management approaches that have been proven to work. A minor emphasis was on identifying successful soil conservation approaches and technologies. Although numerous Chinese experiences were presented, a balanced view of other regions was also provided; these included presentations on activities in Ghana, India, Japan, Jordan, Kenya, Pakistan, Tajikistan, Tunisia and Uzbekistan.

The deliberations of the workshop led to a series of recommendations by the workshop participants regarding integration of land management. Firstly, land tenure approaches play a key role in effectiveness of land management. Secondly, these must be critically linked to water conservation and increased productivity. Thirdly, cooperation at the international level is important and the UN and international agencies can play a vital role in exchange of information and development of new concepts.

I would like to thank the Chinese Academy of Sciences for their generous support of the workshop and very productive contributions to the working sessions. Special thanks must also be extended to Dr. Wang Tao of the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), Lanzhou for acting as the host for the workshop. The productive and informational field excursion in Naiman and the surrounding project sites would not have been successful without the excellent logistical support of the Naiman Station for Desertification Research (NSDR) of the CAREERI and the local government. We deeply appreciate this

cooperation and hope to continue similar collaboration between UNU and CAS in the future.

Prof. Motoyuki Suzuki
Vice Rector, ESD
United Nations University

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A Message from CAS

Dear Mr. Chairman, Ladies and Gentlemen: Good afternoon.

It is my pleasure to deliver the speech on be half the Chinese Academy of Sciences. You are welcome to participate in the International Workshop on "Integrated Land Management in Dry Areas" co-funded by the United Nations University and the Chinese Academy of Sciences.

Land management is a great challenge to many countries for sustainable development and environmental protection. Because of poor management of land use, we have to face the worsening situation of land degradation at present. Land degradation is not only the results of resources-environment system destruction, but also, in turn imposes severe impacts on the social stability and economic development. Therefore, it has attracted worldwide attention. China is one of the countries suffering from severe land degradation, characterized with sandy desertification, in arid and semiarid regions. Sandy desertified land in Northern China was expanded by 1,560 km^2 per year from the late 1950's to the middle 1970's, 2100 km^2 from the middle 1970's to late 1980's and 2460 km^2 in last decade. Sandy desertification is a process of sand drift movement, including wind erosion, transportation and deposition of sand, due to interrupting the ecosystem balance and destruction of vegetation.

Land degradation research in China has experienced several decades of arduous struggle and met with great successes and achievements in both of the academic research and application. Since 1950's, Chinese Academy of Sciences has attached great importance on environment research and protection, especially in sandy desertification control research and prevention.

The Bureau of Sciences and Technology for Resource Development (STRE), Chinese Academy of Sciences is mainly engaged in the basic and applied researches on resources and environment, such as monitoring changes of important ecosystems, biodiversity conservation, pollution and environment protection, and sustainable development of land resources.

STRE has close links with 42 institutes, 15 core laboratories, 18 ministry opening laboratories, five research centers and 15 opening field experiments stations, and the Chinese ecosystems Research Network (CERN) including 34 field stations strategically distributed over China, for long term environment surveying.

STRE has 13,000 research staffs, including 69 academicians and 4000 senior researchers, engaged in the researches of geo-sciences, atmospheric science, oceanic sciences, ecology, agricultural sciences, resource sciences, biodiversity and conservation biology, global change and natural hazard and hazards relief. Meanwhile, the researchers supply academic consultation for individuals, organizations and the governments at all levels.

STRE of CAS has been playing a key role in economic development, resource utilization and environment protection.

Prof. Chen Yiyu
Vice President
Chinese Academy of Sciences

Delivered on his behalf by:
Prof. Fu Bojie
Director
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Progress in Desertification Research in China

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Introduction

Desertification is one of the most serious environmental and socioeconomic problem facing the world today. Because the rapid expansion of desertification has resulted in serious environmental degradation, economic loss, locally unsteadiness political situation and social upheaval, it becomes a hot-spot issue of worldwide concern. During the late 1960s and early 1970s, as the catastrophic drought in the west Africa greatly accelerated the development of desertification, the desertification became a matter of global concern, so that the United Nations Conference on Desertification was held in 1977 in Nairobi, which discussed the necessary scientific research and practical activities for implementing the worldwide 'Plan of Action to Combat Desertification.' Since then, many projects on desertification have been carried out, leading to positive results. In China, thanks to the efforts from scientists and experts, the desertification research has make significant progress during the same period.

Initial Studies of Desertification in China

Investigations into deserts, their transformation and utilization in China were initiated during the 1950s. After the United Nations Conference on Desertification, China's research focus shifted from the original studies of desert formation, evolution and control to the studies of desertification progress and its control; in the meanwhile, the preferential region was shifted from the original arid and hyper-arid zones to the semiarid and part of sub-humid zones where there are relatively better eco-environmental conditions and higher production potential, although they also suffer from desertification.

Desertification research in China mainly includes the following several aspects:

1. Studies on the occurrence, developmental process, types and characteristics of desertification in arid, semiarid and part of sub humid regions in North China.
2. Studies on the present status and distribution features of desertification and environmental changes; and studies on desertification causes, damages and indicator system.

3. Establishment of demonstration bases for desertified land rehabilitation experiment and research under different natural conditions in the selected serious desertification-affected regions.
4. Remote sensing monitoring and mapping of desertification and ground investigation in North China.

From above systematic studies, we have obtained the following major theoretical and practical achievements:

Desertification Concepts

According to the actual situations in China, desertification is defined as land degradation characterized by wind erosion mainly resulting from the excessive human activities in arid, semiarid and part of sub humid regions with frequent wind and loose sandy surface. This concept contains the following implications:

a. Temporally the desertification occurred in the human historic period, especially in the past on century;
b. Spatially the desertification occurred in the arid, semiarid and part of sub humid zones with loose sand surface, where wind season and drought occur simultaneously.
c. Genetically the above-mentioned potential natural factors and undue human economic activities (over-cultivation, overgrazing, over-cutting of forests and overuse of water resource etc.) are the main causes leading to desertification. Man is the maker of desertification and also the victim of desertification.
d. Desertification is a gradual process. Once human activities destroy the fragile ecological balance, wind becomes the driving force to rework the landscape. Therefore, ground features lead to sand drift activities; wind erosion and deposition can be used as landscape marks of desertification processes and indicator of desertification developmental degrees.
e. The developmental trend of desertification is related to desertification intensity, spatial extent, and human and livestock pressure on land. Under the influences of these interacting factors and wind force, desertification self-spreads.
f. As a result, the land surface is gradually occupied by sand dunes, land biological productivity greatly decreases and

large areas of available land resources are lost. However, these lands can also be reversed or self-recovered, which depends on the natural conditions (especially the water condition), landscape complexity of desertified land, and intensity of human activities.

Here we shall clarify and distinguish between the concepts of desert and desertification:

a. The spatial scopes of desert and desertification researches are different. Deserts in China were mainly formed in the different stages of the Quaternary Period and are mostly distributed in arid zones, with vast area, complex and huge aeolian shapes. Desertification mainly occurred in the human historic period, especially in the past one century due to irrational human activities; desertified lands are not only distributed in arid zone but also in semiarid and sub humid zones in relatively small area or showing a patchy and interlacing distribution patterns occurred on dry farmland and rangeland with small and simple aeolian sand features.
b. Deserts are formed by natural factors, while desertification is considered to be man-made product based on the potential natural factors. The former varied with the climatic changes of Quaternary Period; as the climate became cold and dry, the desert expanded and fixed sand dunes turned into moving sand dunes; as the climate became warm and wet, the desert shrank or fixed. Such changes often took place at a large time scale. The development and reversion of the latter generally occur under same climatic condition with in a short time interval. In the past several decades, desertification in North China developed rapidly due to undue human activities rather than the climatic changes.
c. Desert reactivation and expansion or fixation and shrinkage were controlled by climatic changes. Under the modern climatic condition it is impossible to form desert, only by adopting artificial measures can we fix sand land or use the water resources in the desert region, for example, establishment of new oases. The development of desertified land is mainly controlled by human economic activities, through readjusting land use structure and eliminating human disturbance the former non-desert landscape or productivity level can be recovered. If some effective

measures are adopted the restoration process can be accelerated.

Causes of Desertification

Thus far, great progress has been made in understanding the causes of desertification occurrence and development in China. They can be grouped into natural causes and man-made causes. The natural – mechanism of desertification can be summed up into two points. One is abnormal changes of global climate, especially the change of climate in the mid-latitude region toward warm-dry direction, such an ecological background is favorable for the occurrence of desertification. A second one is the presence of adverse natural factors, such as dry climate, large precipitation variability, high loose sand content in surface soil layer, especially the strong and frequent winds form a driving force of desertification development. However, ecosystem in the nature are always have a certain self-adjustment capacity, the slightly damaged ecosystem can be self-recovered and thus maintaining its stability. Accordingly, naturally formed desertification often has a small extent and low severity and can be naturally recovered. Several theories of desertification have been suggested, such as the transitional zone theory, fragile ecosystem theory and global climate change theory, etc.

Desertification mainly occurred during the recent human history, especially in the past one hundred years. The change of natural condition, mainly the climate fluctuation, on the time scale of 100 years is insufficient to cause great environmental change, while the rapidly increased population pressure and economic activities in the same period may greatly disturb and deteriorate eco-environment. Hence these factors are the direct causes responsible for large area of desertification. Man-made causes of desertification include rapidly increasing population pressure, over-cultivation, overgrazing, over cutting of forests and extensive management ways, which destroy vegetation and accelerated the development of desertification.

Based on its characteristics, desertification processes in China can be divide into three types, namely desertification of sandy grassland; reactivation of fixed desert region; and sand dune encroachment. According to field investigation and satellite image analysis, over cultivation-induced desertified land area occupied

25.4%; overgrazing –induced desertified land area 28.3%; over cutting-induced desertified land area 31.8%; overuse of water resources and industrial construction-induced desertified land area 9%; the sand dune encroachment-induced desertified land area under the action of wind force only occupied 5.5%. From this it follows that man-made factors are the most important and active factors affecting the desertification processes.

Desertification Processes

Desertification is a complex eco-environmental degradation process, which occurs as the ecosystem suffers from serious disturbance, ecological balance and vegetation are destroyed. In the research on desertification processes we have made the following achievements.

First, vegetation degradation is mainly manifested in the reduction of plant biodiversity, height, coverage and biomass; in the meantime ground surface occurs small bare spots, perennial grasses gradually decrease, nom-palatable annual species and shrubs or sub shrubs occupy a dominant position, plant communities become simple and sparse, ground bare spots gradually expand to connect to each other. However, if external disturbances are removed, some plants in the shrub lands or inter dune depressions can be gradually restored due to vegetation self-restoration.

Second, soil degradation is mainly manifested in the soil skeletonization, impoverishment and desiccation under the influence of wind erosion. Sandy soil has coarse texture, sand grains larger than 0.05mm generally occupy 95% or more, clay smaller than 0.001mm less than 1%, and has poor cohesion. Once the threshold wind velocity is reached, fine soil particles and organic matter on the non-vegetated surface begin to blow away, rendering the soil coarse and sandy. In the meanwhile, soil water-holding power becomes poor, soil moisture content decrease. Once a drought event occurs, plants become withered or even die. Especially as the wind erosion reaches up to he depth of plough pan, cultivation will become impossible due to serous water and fertilizer seepage.

Third, in aeolian sand landform research the central problem is to elucidate the occurrence and development laws of surface sand drift activities, namely the physical processes of wind-sand stream. Great progress has been made in the following several aspects:

a. The development process of sandy surface features under wind force. Under the interaction between wind force and exposed surface, surface particles begin to roll and initiate saltation or are transported in suspension to form wind-sand stream and further initiate the wind erosion and depositional geomorphologic processes.
b. Reactivation of fixed sand dunes, wind erosion takes place on the windward slope to form reactivated spots-blowout-wind eroded scarps-windward slopes of blowouts becomes gentle and grass coppice dunes occur at the downwind side-small shifting sand patches-semi shifting sand patches-moving dunes and mobile grass coppice dunes-typical moving dune landscape.
c. Sand dune migration processes around the fringe of sandy desert under wind force. As wind blows over the windward slope of moving sand dunes, saturated wind-sand steams forms and much of the sand will be deposited on the leeward side due to vortex disturbance and wind velocity reduction, which make sand dunes advance gradually.

Desertification process is also a sand drift movement process dealing with wind erosion, transportation and deposition, which occur following the man-made upset of ecosystem balance and destruction of vegetation. Such a process contains the following blown sand physical processes:

a. Developmental processes of sandy surface features under the action of wind force;
b. Reactivation processes of fixed sand dunes;
c. Sand dune migration processes around the fringe of sandy desert under the action of wind force.

Desertification Indicators

Desertification is a complex land degradation process. It is held that the desertification indicator should be composed of natural indicators and human socioeconomic indicators. However, until recently no unified global indicator system of desertification was established for lake of consistent selection criteria. According to the actual situations of desertification processes in North China we have established a general desertification indicator and development degree classification system and have been used in the assessment of desertification status and developmental trend and mapping. This system uses the changes of surface features as the main indicators and also considers the changes of soil, vegetation and ecosystem etc. These indicators have widespread representation and are easy to identify. The reason why the changes of surface features are used as the main indicator of desertification is that they are the most obvious landscape marks. Other related indicators such as vegetation cover, plant community structure and composition, biomass, soil mechanical composition, organic matter content, soil effective depth and moisture content etc. can be used as additional indicators.

Monitoring and Assessment of Desertification

According to mapping analysis and calculation of aerial photographs taking in the late 1950s and mid 1970s, desertification in North China was expanding at an annual rate of 1560 km^2. This result is mainly attributed to two situations: one is rain fed farm desertification, which was reclaimed in the steppe and desert steppe regions; another is reactivation of fixed sand dunes due to cultivation, overgrazing and uncontrolled removal of natural vegetation.

By the late 1980's, desertified land area in China has reached 33.4×10^4 km^2, of which very severely desertified land area occupied 10.2%; severely desertified land area 18.3%; on-going (moderate) desertification land area 30.5%; slightly and potential desertification land area 41.0%. As viewed from the development trend, desertification in local places has been reversed however, on the whole it was still expanding. From the mid 1970's to the mid 1980's, desertified land area increased by 2.1×10^4 km^2, or an annual increase of 2100 km^2. These are mainly distributed in three regions. First is the over cultivation regions in Bashang area of Hebei Province, Ulanqab grassland and Qahar grassland in Inner Mongolia. Second is the reactivation regions of fixed sand dunes in east Korqin Sandy land of Inner Mongolia due to overgrazing, over cutting and over cultivation. Third is the energy source base in the sandy steppe region, for example, the Shenfu coalfield etc. These are also the key regions needed to be rehabilitated in the future.

Rehabilitation of Desertification

According to natural and economic characteristics, desertification developmental trend, problems and experiences in the utilization and rehabilitation in North China, the rehabilitation of desertification should seek an unified objective of ecological benefit, economic benefit and social benefit; follow the ecological principle of conservative use and multi-project complementation, and rehabilitation should be integrated with utilization. So far as concrete measure are concerned, in the mixed agro-pastoral desert region, with scattered ecological household as bases, such measures as grazing exclusion, readjusting rain fed cropland use structure, expanding forest and grass land area, establishing farmland forest net and inter dune patchy forest are adopted. In the grazing grasslands, efforts should be made to define rational stocking rate, carry out rational rotation grazing, establish artificial grasslands and fodder bases, dig drinking wells and build roads. In the arid zones, an overall planning with water basin as an unit should be worked out, to rationally distribute water use, establish farmland forest net inside oases and tree shrub sand break belt around the margin of oases and set up mechanical sand fences to form a comprehensive protection system. In addition, the traffic lines in the dense sand dune regions should be protected by the protective system consisting of sand fence and sand-fixing plants, laying emphasis on fixation in combination with block and diversion.

Through many years of studies of different rehabilitation patterns in several experiment plots of Lanzhou Desert Research Institute, Chinese Academy of Sciences we have obtained the following successful examples:

Example 1. Changes before and after rehabilitation in the Naiman Banner experiment plot in Inner Mongolia. After rehabilitation the village's 1000 hm^2 of shifting sand land decreased to 330 hm^2, vegetation cover increased from 10% to 70%, grain yield increased from 150000 kg to 450000 kg, and per capita income increased from 174 Yuan/year to 1290Yuan/year.

Example 2. Changes before and after rehabilitation in Yanchi experiment plot in Ningxia. Through rehabilitation the village's 4822 hm^2 of desertified land were entirely controlled, of which 667 hm^2 of shifting sand land transformed into woodland; vegetation cover increased from 30% to 50%; grain yield increased from 139,000 kg to 219,000 kg; and per capita income increased from less than 500 Yuan/year to 1175 Yuan/year.

Example 3. Changes before and after rehabilitation in Linze experiment plot in Gansu Province. Before rehabilitation shifting sand posed a serous threat to the oasis. Since the protective forest belt was established around the experimental plot in 1975, besides the old oasis, some 3300 hm^2 of new oasis have been protected. Two new villages, Guangcheng and Haowa, have been set up, and about 125 peasant households have been moved to these two villages. They have transformed the original desertified land into stable high-yield field and per capita income reached 2000 Yuan/year. Such practices have been popularized to 27000 hm^2 of desertified land in Hexi Corridor region.

Example 4. Changes before and after rehabilitation in Yucheng experiment plot in Shangdong Province. Through four years of comprehensive rehabilitation some 4100 hm^2 of blown sand land have been turned into fertile cropland with protective forest net and irrigation canal. Sand drift disasters have been under control, therefore the land output is about 4.4 times as large as the land investment. Such practices have been popularized in Dezhou and Liaocheng regions, Shangdong Province.

As described above, Chinese scientists have made some encouraging achievements in the desertification research field and provided scientific basis for working out the desertification control planning of the country. China's experiences have attracted widespread attention from international communities, especially in developing countries. Entrusted by UNEP and ESCAP the Lanzhou Desert Research Institute, Chinese Academy of Sciences has organized 12 raining seminars and international symposiums on desertification control and sent expert group to Mali to conduct cooperation and work out desertification control planning.

Progress in Desertification Research of China During the Past 10 Years

Fundamental Research on Desertification

For blown sand physics, significant progress have been made, including the dynamics of wind-sand, gas-solid two phase flow, aeolian bed form movement theories, soil wind erosion theory, theory of similarity concerning aeolian sand experiment, and sand drift control engineering. This research contributes to a better understanding of the physical principle of desertification. In particular, some clear images of single grain movement have been obtained and the related mathematic models have been established; the physical and mathematic models of wind-sand, gas-solid two phase flow movement were preliminarily established on the basis of classic multi-phase fluid mechanics; and a set of theoretical parameters of similarity on sand drift experiment were put forward.

For desert evolution and climatic changes, much work has been conducted on desert deposits, types, climatic features and their environment significance. Deserts were divided into three ages, their spatial distribution patterns, regional differentiations and development patterns were studied, and the emphasis was placed on the studies on the climatic environments and formation causes of pre-Quaternary red desert and Quaternary yellow desert. In addition, the developmental history, present status and future development trend and countermeasures of modern desertification were explored.

Several comparative micrometeorological studies on farmland, grassland and sandy land showed that desertification has significant influences on micrometeorology. In the desertification processes, surface radiation balance, heat balance and soil water balance are greatly altered due to the change of underlying surface. For example, wind velocity profile over vegetated area shows a logarithm distribution, surface boundary layer thickness in daytime is 2.7m, in night 5m or more, and surface drag coefficient 3.2×10^{-3}. Wind velocity profile over moving dunes shows a logarithm distribution in might but bend toward IN axis in daytime. Surface boundary thickness is less than 0.7m and surface drag coefficient 1.9×10^{-3}. As a result, sand dune surface receives greater wind stress and sand grains are prone to deflation. In the desertification process, with destruction of vegetation surface reflectivity sharply increases, while net radiation and latent heat exchange decrease. Surface reflectivity over non-desertified land surface is generally less than 0.15-0.20, the figure over degraded land surface ranges from 0.25-0.30 and shifting sand area 0.35-0.40. With the establishment of artificial vegetation on sand dunes, he surface reflectivity decreases and vertical wind stress reduces. The presence of vegetation dissipates much of airflow momentum, rises temperature and humidity protects sand surface from direct deflation and therefore is favorable for sand dune stabilization.

Dynamic Monitoring and Assessment of Desertification in North China

Much work has been conducted on the development, distribution and disastrous processes of desertification in North China using remote sensing and GIS techniques, making desertification research enter quantitative analytical and economic assessment stage. Based on a 1:4000000 map of desertification disaster risk, a pilot run system of desertification disaster monitoring and assessment has been established. Research shows that effective desertification monitoring indicators are:

a. Natural indicators – changes in wind eroded land, sand land or sand dunes, dust storm, seasonal and yearly changes in precipitation, wind velocity and direction, effective soil layer thickness, organic matter content, table and quality of ground water, and surface reflectivity, etc.;
b. Biological and agricultural indicators – vegetation cover, biomass, main plant species distribution and frequency, land use status, crop yield, livestock composition and quantity, etc.;
c. Social indictors – population quantity and structure changes and trends, residential form, public health index, mandatory or special policies, etc.

Desertification, Vegetation Succession and Landscape Ecological Research

Recent studies on vegetation succession research show that sandy land vegetation succession differs from that of grassland; the former is mostly associated with desertification degrees. Sandy land vegetation succession contains both gradual and sudden processes and is controlled by desertification degree and its own structural function. Among different types of desertified land vegetation often shows a sudden change, on the same type of slightly desertified land vegetation often shows a gradual change, while on the seriously desertified land shows a sudden change. On the overgrazing-induced desertified grassland biodiversity, vegetation cover, grass height and yield decrease rapidly; perennial grasses firstly disappear, followed by palatable annual forages, and are replaced by non-palatable plants; then small bare spots occur on ground surface and gradually expand to connect to each other, and finally led to large area of desertification. Grass desertification process resulting from sand drift damage and water condition deterioration and overgrazing-induced desertification have some similar features but also exhibit obvious differences. For the former, from north face slope to south face slope of sand dunes, from wet land to dry land and from fixed dune field to moving dune field vegetation deteriorate rapidly, and the deteriorating velocity is much higher than the latter, however vegetation height and yield do not necessarily decrease. Under favorable conditions degraded vegetation on sandy land may occur positive succession, namely he species composition, vegetation cover and height increase obviously, and the percentage of herbage in he community increase greatly.

Research on landscape ecologicy shows that desertification process is closely related to the changes of landscape structural characteristics. Viewed from landscape scale, initial small-scale desertification is related to surface erosion and deposition processes, but does not affect landscape characteristics. As desertification reaches moderate degree, both sand dune stability and landscape characteristics would change but do not affect landscape attribute. As large-scale desertification occurs, landscape elements (patches, for example) will split into different attribute landscape elements. Among the artificial sand fixation area, enclosed protective area and moving sand dune area, the first area has most complex spatial pattern and high landscape heterogeneity, followed by enclosed protective area, and moving sand dune area has simplest landscape pattern. In the desertification developmental process, sandy land landscape pattern tends to become simple; in the desertification reversion process landscape pattern tends to become complex and heterogeneity increases. Patches in different landscape types show different laws in changes. In the artificial sand fixation area patch diversity increases, including fixed sand dune, semi fixed sand dune, semi shifting sand dune and moving sand dune, hence patchy pattern tends to become complex due to the influence of sand stabilization measures. In the enclosed protective area spatial structures of foxed sand dune and moving sand dune patches are most complex and have high patch pattern diversity due to the influences of seasonal grazing, cutting and natural restoration. Semi fixed and semi shifting sand dunes have lower patchy diversity and simple spatial structure. Accordingly, we can assess the desertification developmental degree on different time and space scale in accordance with desertification trend and landscape indicators.

Research on Desertified Plants Stress Physiology

In the past, the research mainly focused on physiological characteristics of desert plants. In the recent ten years, considerable attention has been paid to the relations between desertification and plant physiological changes and plant adaptive mechanism to desertification. Some useful conclusions have been obtained from the researches such as plant anatomical feature, photosynthetic rate, protective enzyme system, osmotic regulator, plasma membrane permeability and membrane lipid per oxidation and plant stress succession etc. For example, under dry and high-temperature conditions, desert plants show a bimodal photosynthetic curve and lower photosynthetic rate; under wet condition they show a unimodal photosynthetic curve and higher photosynthetic rate. Plants with higher moisture content have higher photosynthetic and transpiration rates, and vice versa. Under dry high-temperature conditions water loss of strong drought-resistant plants is less and slow, once regains water, soluble sugar and praline contents increase rapidly, activity of protective enzyme improve rapidly and shows a negative correlation with membrane lipid per oxidation. For weak drought-resistant plants the situation is just contrary. During the process from shifting sand land turning into fixed sand land, plants evolve form drought-avoiding species to physiologically drought-resistant species, from sand drift-resistant species to drought-resistant species and from single propagating way to diversified propagation way.

Research on the Influence of Desertification on Ecosystem

Research shows that in the farm desertification processes surface soil become coarse, soil fertility and water-holding capacity decline, diurnal changes of surface temperature becomes intense, plant photosynthetic efficiency drops, plants become weak and low and have lower water-production efficiency even under normal precipitation or irrigation conditions. As a result, the productivity of ecosystem falls, even leading to collapse of he farmland ecosystem. As for the grass land ecosystem, the desertification intensifies sand drift activity, deteriorates microenvironment and reduces wind-sand resistance; hence high and broad-leave plants disappear, biodiversity decline, community structure become simple and sparse, vegetation cover and leaf area index drop, energy input in grassland ecosystem decreases, material conversion is limited, hence productivity reduces. As for the artificial ecosystem on shifting sand land, with the increase in vegetation cover soil moisture condition become worse and thus affecting the growth of pioneer plants. The formation of micro biotic curst also hinder s germination of psamaphytes, as a result pioneer plants decline and are finally replaced by other species.

Research on High-Efficiency Use of Water and Land Resources

In the recent ten years, some thematic research has been carried out. This mainly focuses on water resources and forest construction in Northwest China, carrying capacity of water resource in Hexi Corridor regions, classification of blown sand soil, arid soil and irrigation-warping soils to meet the demand of regional development and environmental rehabilitation in desertified region. In the meantime, with river basis as an unit a series of research studies on resources use, human activity, economic development and environmental issue were carried out, put forward rational use principles of water and land resource, and worked out the development planning of several typical river basins. Other research projects include influences of climatic change on dry land agricultural system and water resources, water balance and sustainable development of desert oases, economic development and eco-environment protection in Hexi regions, experiment and demonstration of high-efficiency rain-harvesting agriculture and ecological agriculture of sandy land in Huang-Huai-Hai Plain, etc.

Progress in Desertification Rehabilitation Models and Techniques

In the recent ten years, in accordance with the demand of national economic and eco-environmental construction, some new comprehensive rehabilitation models and techniques of desertification were development. A widely used model is the three-level village, hamlet and household comprehensive rehabilitation model consisting of "ecological net", "multivariate system" and "micro biosphere". It is used in the semiarid mixed agro pastoral region of Naiman. According to this model, a large windbreak and sand-break forest should be established in the village; such measures as planting structural readjustment, grazing exclusion, establishing sand-break forest, constructing capital farmland and developing agro forestry and animal husbandry should be adopted at hamlet level; and at household level scattered peasant households should set up farming districts in inter dune depressions with better water and heat conditions, as well as forest belt, buffer grassland and grazing land. Such three-level model has proved to be an overall and effective desertification rehabilitation system. Other newly developed desertification control and sandy land farming techniques include rice cultivation technique in film-bottomed sandy land in semiarid regions, wheat cultivation technique in sandy land, licorice and Chinese ephedrine cultivation techniques in alpine cold region, water-saving farming in oases and brackish water irrigation technique, etc.

Prospect for the Desertification Research in China

Blown Sand Physics and Desert Environment Research

This is an area of fundamental research on desertification. Relying on field experiment stations, indoor wind tunnel and field wind tunnel we will thoroughly study natural factors and human factors, feedback effect of desertification on these factors, their contribution on different time scales to the mechanism of desertification processes; establish identification and operational mechanism models of various driving factors in modern desertification processes; in combination with mass and energy flow law at adjacent ecosystem interface and the research results of future human activity and global change trend, establish the dynamic model of desertification processes coupling with natural factors, human factors and desertification to precisely predict the future development trend of desertification.

Ecology of Desertified Land Restoration

The following research studies will be conducted:

a. The ecological process of dry land fragile eco-environmental evolution and biological mechanism of desertification;
b. Structural function, energy flow, mass flow and information flow of different-level and different-scale ecosystem;
c. Dynamic stability of landscape pattern and biodiversity time-space changes and their maintenance mechanism in desertification and its reversion processes; and
d. Adaptive mechanism of desert plants species to harsh environment.

Utilization of Water and Land Resources for Agricultural Sustainable Development

Main research projects in this area include:

a. Different time and space scale water balance in typical regions, ecological risk analysis of water and water exploitation in desertified regions, changes in environment and resources under the background of global changes and their quantitative prediction;
b. Optimization allocation of water and land resource and transform models from resource advantage into economic advantage in desertified regions; and
c. Agricultural engineering techniques, cultivation techniques, cultivation techniques of high-yield crops and regional sustainable development strategies.

Desertification Reversion Process and Rehabilitation Models

Various desertification reversion strategies, rehabilitation models and technical systems of different types of desertification land will be studied at the field experimental stations in different zones, then establish demonstration plots and use successful techniques in the regional desertification control.

Establishing Desertification Monitoring, Assessment, Decision-Making and Management System

Further studies will be conducted employing 3S techniques and other high techniques to establish the resource and environmental information system, realize rapid information processing and upgrade and serve the regional sustainable development.

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2

Wind Erosion and Soil Conservation in Arid and Desertified Tunisia

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Geography of Tunisia Adjacent to the Sahara

The zone adjacent to the Sahara in Tunisia covers approximately 30,000 km^2. The annual rainfall ranges between 100 and 200 mm. This rainfall, which is accentuated by dry winds and is highly variable, prevails mainly between May and September, during the cold period and the drought. The thermal regime is quite variable. The average maximum temperature of the hottest month (July) varies from 32 to 36°C, according to the lower end of the Mediterranean arid climate. Because of different soil types, the redistribution of rainfall through runoff, and the more or less strong demographic pressure (cultivation, overgrazing, etc) a very limited steppe vegetation prevails.

Since the beginning of this century and in particular during the last few decades, rapid changes of the landscape in southern Tunisia have been observed, due mainly to population growth and human settling. Changing styles of living and rural development are accompanied by changes in the land tenure system and the quantitative and qualitative use of natural resources (Floret and Pontanier 1982; Le Houerou 1969 and 1990; Talbi 1993).

In the past, this area was used for extensive grazing (by sheep, goat, and camel) on communal rangelands, and for traditional systems of cereal cultivation, mainly in the higher rainfall zones. Due to the rapid settlement of nomadic populations and the ownership of collective lands, new forms of natural resource management have been developed. This is illustrated by the gradual abandonment of nomadic systems, establishment of home gardens, and the rapid extension of tree-and cereal-crop cultivation at the expense of pasture lands. This is due mainly to the introduction and general mechanization of farmin, which permits the rapid and less expensive clearing of large areas in the steppe (Khatteli 1981, 1984).

Adoption of this aggressive technology for cultivating the sandy steppe lands, which are the most attractive for cereal and tree-culture, promotes accelerated wind erosion. This rapid extension of cultivation at the expense of pasture land has led to a decrease in the traditional pasture zone. Sheep, still found in significant numbers, are progressively pushed to graze on lands with reduced numbers of living species and low biomass, which also leads to land degradation. This process is of serious concern, as the lands are particularly prone to wind erosion, which removes the thin topsoil and leads to the formation of dunes (Ben Dali, 1987; Akrimi *et al.*, 1988 ; Akrimi and Abaab, 1991).

Settlement is leading to the loss or dispersal of huge flocks, which are replaced by smaller units that graze year-round close to inhabited areas. This also provokes localized overgrazing and an accelerated degradation of the environment in the vicinity (Floret and Pontanier, 1932).

Sheep grazing is more or less a semi-nomadic practice, easily adapted to a spatial and temporal variability of rainfall and grazing resources. Thus, the deterioration of the ancient system of management of rural areas is leading to changes, sometimes irreversible, in the ecological equilibrium that existed in the traditional management systems of land and vegetation. Natural resource management is thus disturbed, and the degradation process increased. This is demonstrated by the decreased biological productivity of ecosystems, resulting in a lower standard of living for the inhabitants (Floret et al. 1976). Floret *et al.*, have shown that if the current exploitation of marginal lands continues past the year 2000, degraded lands will increase from 35 to 65% and the productivity of the ecosystems will decrease by 35%.

Fundamental Knowledge of Wind Erosion Processes

The research that we have undertaken has provided several useful results concerning the fundamental processes of wind erosion and the implementation of practical solutions, both curative and preventive, to counter wind erosion.

Studies carried out at different research stations (Ben Gardane, Dar Dhaoui, Sidj Makihouf, Menzel El Habib, and Nouiel) demonstrate that desertification, where sand encroachment poses the most serious problem, should not be considered as an unstoppable progression of sand masses from the Sahara. In fact, this is a local phenomenon – discontinuous, diffuse, and non-generalized – that occurs at all places in a vulnerable and marginal environment where the delicate equilibrium is disturbed by excessive and indiscriminate use by human populations (Khatteli, 1981,1982).

In fact, the movable sand dunes that are encountered frequently near oases, cultivated lands, and villages are formed following the destruction of vegetative cover due to multiple anthropogenic effects (eradication of woody scecies, overgrazing, crop cultivation, etc.). Their progression in the direction of the Sahara in general, and the Erg Oriental in particular (and not the other way as we previously believed), is due to the dominance of active winds that blow from the east, southeast, and the north over the winds that originate from the west and the south (Khatteli, 1981 ; Khatteli and Bel Haj, 1993).

At the planning level, the results of our study on wind dynamics and sand movement can provide practical solutions for efficient control of movement of sand dunes on the local scale, or even in terms of movement of the dunes. Mechanical windbreaks can be oriented perpendicular to the axis of sand displacement, and the implementation of mechanical stabilization of sand dunes can be undertaken when winds are relatively quiet. However, maintenance operations and the re-erection of the fences installed should be done during the windy periods in order to avoid their burial under the mobile sands (Khatteli, 1996).

Low wind breaks (maximum height of I m) with a homogeneous permeability and without and opening at the base, are highly recommended to combat moving sand dunes.

Combatting Wind Erosion

In our research, we wanted to demonstrate that the wind erosion in our zone is an anthropological phenomenon which, once initiated, tends to become more extensive and even encroach on the more stable environmental zones. The experiments carried out at the research stations have demonstrated that it is possible to combat this degradation, at the curative as well as the preventive level.

The Curative Control of Wind Erosion

Olive Crops Affected by Sands

The sand encroachment of olive crops results from excessive cultivation of soil with a disk harrow, which pulverizes the soil and renders it more vulnerable to wind erosion. This is manifested by the disappearance of olive crops where the deflation and formation of movable sand dunes occurs, or where sand deposition occurs. To combat this phenomenon, mulching was employed, consisting of spreading plant residue over the soil surface after leveling the dunes (Kharteli, 1984). The erosion process has slowed down markedly, and no new dune formation has since occurred at this site.

Three types of plant residue were tested. The twigs of *Artemisia cainpestris* were found to be more suitable for the fixation of the mobile dunes than the other two (*Rhanterium suaveolens* and palm leaves). This was due to their application efficiency, pastoral and economic value, and availability in sufficient quantities on the degraded lands and fallows in the study zone.

It is strongly recommended that the disk harrow be replaced by a tooth-harrow plowshare, or blade-harrow, ad of which provoke less degradation. The maintenance of natural plant strips between the olive trees and their utilization as wind breaks is also highly recommended.

Land Covered by Degradation

The research done at Menzel El Habib on a degraded steppe covered by *Rhanterium suaveolens* under multiple anthropogenic effects (overgrazing and removal of woody species) illustrates the positive impact of measures taken to combat wind erosion. The ecological evolution of the study zone under the effect of the protective measures is demonsnated from a geomorphological stand point in terms of:

a. A spatial extension of nebkas at the expense of mobile dunes and the denuded zone.
b. A decrease in the susceptibility of the land to wind erosion.
c. A general tendency towards the establishment of an eco-pedomorphological equilibrium.

The protection of degraded land subjected to intense wind erosion processes can be envisaced as an efficient and less expensive method to combat wind erosion, provided the limit of its irrversibiiity has not yet been reached.

Mechanical Fixation of Mobile Dunes

A trial at the Sidi Maklhouf station examined the use of dry wattling (living brushwood) for rapid and effective stabilization of mobile dunes. Five treatments (including a control) were studied, and the following conclusions drawn:

a. Wattling arranged either in 20 m squares (continuous pattem) or in rows spaced 20 m apart (across the main wind direction) were the most effective treatments in terms of the quantity of sand trapped and the stability of soil surface inside each plot. The 40 m squares were less effective, but still resulted in improvement. Wattling rows planted 40 m apart were the least efficient, although they were significantlv superior to the control (no intervention).
b. In terms of cost/benefit, the 20 m parallel rows were better than the 20 m squares because they were only half as expensive. This allows us to evaluate the actual cost of mechanical stabilization of dunes carried out by the regional technical services of the General Directorate of Forestry.
c. The first six months of the trial were characterized by instability inside the different plots, which damaged the fixed plants. It is thus advisable not to begin tree planting during this period to avoid the burial of young plants due to sand deposit, or their removal due to deflation. Work during this period should be oriented towards the cleaning and care of the fence. Replanting should not be started until after the second year, or, at a minimum, six months after the installation of the plot.
d. The dune soil, especially when it is a little mobile, generally constitutes a favorable atmosphere for the development of natural vegetation, thanks to its capacity to retain soil moisture at shallow depths. It responds well to protective measures and may be sufficient for soil-surface fixation. This procedure will prevent re-afforestation resulting in reduced expenses for the fixation of the mobile dunes and the restoration of the degraded lands.

Preventive Measures

The results of the experiments carried out in Dar Dhaoui on the tools for soil cultivation, as well as natural plant strips for the prevention of wind erosion on lands cropped to cereals, clearly point out the extreme fragility pf arid ecosystems, notably those on sandy soils. Inappropriate exploitation of the natural resources in this zone (water, soil, vegetation) provokes wind erosion which, once initiated, feeds on itself and intensifies due to anthropogenic as well as climatic factors.

Crop cultivation can be regarded as a factor of soil degradation in south Tunisia because wind erosion is provoked on soils that are cultivated. This erosion is at its highest when the land is cultivated by disk harrow. Utilization of the disk harrow on sandy soils cannot be tolerated unless the soil roughness is improved by the addition of plant residues or by keeping uncultivated natural vegetation strips between the cultivated strips. If the first solution cannot be achieved, because it requires an investment to provide plant residue (hay, straw, or any other natural residue available locally), the second solution of natural vegetation strips is attractive to the farmers because it does not require any investment. It can be easily implemented on a large scale. Strips 10-20 m wide are more efficient than strips 5 m wide, because they are more effective in decreasing wind erosion, and also help achieve a small increase in barley yield. In addition to the ecological benefits (conservation of natural vegetation which is nearing extinction because of land clearing). The uncultivated strips also provide livestock feed, thanks to the pasture productivity.

The tooth harrow, (tiller) and the blade (sweep), even though they significantly reduce wind erosion in comparison to the disc harrow, cannot substitute for the latter in the cereal zone because of the low yield of barley obtained in fields where they were used. Therefore, their utilization is recommended in horticultural fields (i.e., for olive cultivation). The plowshare is *a priori* the most appropriate tool because it results, on average, in a three-fold reduction in soil loss compared to the disk harrow, while producing an annual harvest closer to the mean yield.

Research results achieved on wind erosion in the arid and desertified Tunisia have been utilized at several locations:

a. The Regional Technical Services of the Directorate General of Forestry made use of our results to select the most permeable mechanical windbreaks and their onentation relative to the dominant active winds. These are being implemented at Mednine, Gabes, and Kebili.
b. The farmers at Ben Gardane and at Zarzis used our results regarding the maintenance of uncultivated strips between cultivated lands and the progressive replacement of the disk harrow by the tooth harrow, particularly in olive fields.
c. Dune fixation in olive fields encroached by sand using the mulching technique has started to interest some olive farmers in the Zarzis region.

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3

An Overview of UNESCO's Activities in the Field of Dryland Conservation, Management and Rehabilitation

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Introduction and historic overview

The United Nations Educational, Scientific and Cultural Organization (UNESCO) was probably the first United Nations agency that took up the challenge of specifically addressing scientific matters in and problems of drylands. As early as 1951, an international study and research programme on arid and semi-arid zones was launched by UNESCO which was raised to a "major programme" within UNESCO from the period 1957 – 1964. Its hallmark was a holistic and interdisciplinary approach comprising both the natural and the social sciences needed to better understand the dynamics of dryland ecosystems.

In 1968, UNESCO organized the "International Biosphere Conference" in Paris in collaboration with FAO, ICSU, IUCN and other partners, which proved to be a landmark event. This conference recommended the launching of a world-wide research programme on the interactions of "man" and the "biosphere". The UNESCO General Conference, at its session in 1971, endorsed this recommendation and officially launched the "Man and the Biosphere (MAB) Programme" accordingly. The earlier UNESCO Major Project on "arid and semi-arid zones" was included in the MAB Programme and become the focus of one of several ecosystem oriented research themes (others were tropical forests, coastal areas, mountain ecosystems etc.). Based on the positive experience of holistic and interdisciplinary research of the Major Project on arid and semi-arid zones, this approach was also adopted by the MAB Programme and has shaped the distinctive feature of MAB.

In 1974, another major scientific programme of UNESCO came into being, the International Hydrological Programme (IHP). This programme is also concerned with the drylands and intends to upgrade countries' knowledge of the water cycle and thereby increase their capacity to better manage and develop their water resources. It also aims at the improvement of the scientific and technological basis for the development of methods for the rational management of water resources, including the protection of the environment.

In this paper, a specific emphasis is given to the Man and the Biosphere (MAB) Programme and its activities in dryland ecosystems so as to illustrate the multiple facets of drylands research and conservation.

The Programme on Man and the Biosphere (MAB)

The MAB Programme is an international environmental research and conservation programme. It aims at developing the basis, within the natural and the social sciences, for the sustainable use and conservation of natural resources and biological diversity, and for the improvement of the relationship between people and their environment globally. In doing so, it encourages interdisciplinary research, demonstration and training in natural resource management. MAB contributes thus not only to better understanding of the environment, including global change, but to greater involvement of science and scientists in policy development concerning the wise use of natural resources. While the name of the programme may entail a juxtaposition of "man" versus "nature", the thinking of the programme today rather tends towards and integration of people within the biosphere since humans are now considered as an integral part of any given ecosystem.

UNESCO's intergovernmental structure gives MAB the potential to help national governments support the planning and implementation of research and training programmes. This association focuses on the most urgent needs of countries as defined by their own scientific community and decision-makers. Thirty-four countries are represented in the International Co-ordinating Council of the programme. MAB National Committees (mostly under the ministries of the environment) have been established in 144 countries comprising decision-makers, natural and social scientists, as well as environmental conservation specialists. Currently, there are MAB Programme activities in over 110 countries around the world. The programme, therefore, provides an immense network for information exchange on dryland studies and their conservation.

When the MAB Programme came into existence some 30 years ago, it was designed around a total of 14 MAB Project Areas, which are listed in the box below. It is noteworthy that the MAB Programme incorporated an ecosystemic approach where the impact of human activities on a given ecosystem was in the centre of interest.

The 14 MAB Project Areas from 1971 – 1991:

1. Ecological effects of increasing human activities on tropical and subtropical forest ecosystems.
2. Ecological effects of different land uses and management practices on temperate and Mediterranean forest landscapes.
3. Impact of human activities and land use practices on grazing lands: savanna and grassland (from temperate to arid areas).
4. Impact of human activities on the dynamics of arid and semi-arid zones' ecosystems.
5. Ecological effects of human activities on the value and resources of marshes, rivers, deltas, estuaries and coastal zones.
6. Impact of human activities on mountain and tundra ecosystems.
7. Ecology and rational use of island ecosystems.
8. Conservation of natural areas and of the genetic material they contain.
9. Ecological assessment of pest management and fertiliser use of terrestrial and aquatic ecosystems.
10. Effects of man and his environment of major engineering works.
11. Ecological aspects of urban systems with particular emphasis on energy utilization.
12. Interactions between environmental transformations and the adaptive, demographic and genetic structure of human populations.
13. Perception of environment quality.
14. Research on environmental pollution and its effect on the biosphere.

During the first twenty years of the MAB Programme, in particular six project areas received particular attention from the MAB community. These were the ones related to tropical forest ecosystems, mountain ecosystems, coastal zones and islands, Mediterranean ecosystems, urban systems, and arid and semi-arid zones. The latter gave rise to a several large-scale pilot projects on arid lands in Africa:

- Integrated Project on Arid Lands in Kenya (IPAL-Kenya) with follow-up projects Kenya Arid Lands Research Station (KALRES) and Turkana Resources and Evaluation Monitoring Unit (TREMU);

- Integrated Project on Arid Lands in Lesotho (IPAL-Lesotho);
- Integrated Project on Arid Lands in southern Tunisia (IPAL-Tunisia);
- Training and education on integrated pastoral management in the Sahel (FAPIS project);
- Strengthening of scientific capacities in the agro-silvo-pastoral domain (CILSS Member States, West Africa);
- Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG).

Common to all these projects was the focus on capacity-building for national and international scientists through interdisciplinary studies on the environment. Two examples of MAB pilot projects in arid lands are mentioned here to illustrate the integrated approach of these projects.

Integrated Project on Arid Lands (IPAL) in Kenya

The IPAL-Kenya project in northern Kenya's Marsabit and Turkana districts lasted from 1975 to 1984 and generated two follow-up projects, KALRES and TREMU, which terminated in 1991. Fifteen years of applied field research on the structure, functioning and dynamcis of dryland ecosystems brought a multitude of scientific findings and publications to the fore which fill several meters of book shelves. The following, therefore, provides only a glimpse of the many ramifications and results of the project.

The starting point of the project was the increasing sedentarization of the nomadic Rendille and Turkana nomads in northern Kenya. Due to well-meant development aid schemes initiated by churches and other aid organizations in the first half of the 20th century, schools and pharmacy dispensaries were established in an area that hitherto had offered no physical and social infrastructures to improve the livelihoods of people living in a very harsh climatic and desert environment with extreme diurnal temperature ranges, little and erratic rainfall and a fragile vegetation cover. Because of the introduced amenities (schools and pharmacies), parts of the the nomadic population created permanent settlements around the new villages, thus putting an enormous pressure on the fragile dryland ecosystem. In particular the grazing pressure of their livestock led to an intensification of vegetation removal and soil erosion exacerbating human and livestock casualties in periods of drought spells.

The UNESCO IPAL-Kenya project, therefore, focused on questions of the carrying capacity of dryland using an integrated approach that analyzed the natural and the social environment of the nomadic Turkana and Rendille populations. For example, the project owned its own camel herd of about 20 individuals which served as control group *vis-a-vis* camels owned by the nomads that received free veterinary treatment from the project. Growth dynamics, annual and seasonal milk production, fodder selection and eating behaviour, tick infestation and health conditions in general were among the many topics that were studied.

The dwarf shrub Indigofera spinosa received particular scientific study. Despite its spines, the shrub can be eaten by livestock, in particular browser like goats and camels. IPAL-Kenya scientists around Dr Gufu Oba discovered that browsing the plant was actually beneficial to its growth dynamics. They concluded that the shrub should be browsed – and thus defoliated – to up to 30% which seems to be the best rate for reducing transpiration rates and conserving water availability in the soil. Moreover, the plant should be browsed in particular during the dry season, as the reduced foliage again helps to conserve water for the soils and the plant itself.

These results can be formulated into important management guidelines for the nomads to enhance sustainable seasonal range management. The project strived to convey such results to the nomads, however, at times with varying results. One of the main topics was that nomads should not so much favour the sheer number of individual livestock, but rather quality livestock: fewer animals per area unit would be less destructive to fragile dryland environments and higher quality animals would fetch higher prices on the markets. However, when one of the nomad field assistants married, it was a question of pride and honour for the family to provide him with the maximum number of livestock that they could afford as dowry and gift. This anecdote shows that it is relatively easy to work out scientific solutions to adequate and sustainable pastoral management in the drylands, but that socio-cultural parameters often impede the effective implementation of scientifically-tested and sound land management practices.

Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG)

The Cooperative Integrated Project on Savanna Ecosystems in Ghana (CIPSEG) drew lessons of the earlier IPAL-Kenya project and tried to base environmental conservation on socio-cultural parameters. The project, which was carried out in northern Ghana's savanna region from 1993 – 1997, in fact used traditional belief systems and "natural sacred groves" to study, in an integrated and inter-disciplinary manner, sustainable development and dryland conservation.

In Ghana, as in most other African countries, rapid population growth and expansion of economic activities have lead to deforestation and degradation of the environment. In many parts of the country, the natural vegetation has been seriously affected by bush fires, agricultural cultivation, overgrazing, fire wood cutting and even urbanisation and village sprawl.

Although environmental degradation is widespread in northern Ghana which is a dry sub-humid savannah of the Guinea type, small pockets of residual closed canopy forests remain near human settlements. Many of these forest pockets are, in fact, "sacred" groves, which have survived environmental degradation because of religious belief systems. Almost all existing sacred sites in Ghana have been, and continue to be protected by taboos, traditional beliefs and some local customs. Because of the reverence people attach to the sacred groves, people's general perception of the groves have resisted encroachment or unwarranted exploitation of resources within the sacred sites.

With this background situation, UNESCO carried out the CIPSEG-Project, whose aim was to assess whether the sacred groves could be indicator sites for the potential natural vegetation of the savannah area. Could they give an idea of how the savannah of the Guinea type looked like before human pressure on the savannah grew too strong? In this vein, the project's goals was to develop a scientific knowledge base on the relict sacred groves ecosystems and to study the sacred groves in terms of their plant and animal species composition. This knowledge base was then geared towards achieving the second main aim of the project: to restore the adjacent and degraded savannah areas by using native plant species from the sacred groves' gene-pools. The project, therefore, had both a scientific orientation (study of the sacred groves' genetic resources), and a development orientation (rehabilitation of degraded environments).

In order to address these two main objectives, several scientific teams were set up which worked in an interdisciplinary approach. For example, the Botany Department of the University of Ghana carried out plant inventories of the three selected sacred groves. The Geography Department of the same university looked into the overall land use systems of the three districts in which the sacred groves are located, with a view to elaborating environmentally sound management plans. Apart from ecological research, the project also attached great importance to the socio-cultural dimensions of the sacred groves. The Centre for National Culture in Tamale undertook in-depth studies of the traditional beliefs which had led to the protection of the sacred sites; the same Centre also analyzed the sacred groves' functions for ceremonial purposes performed by the priests. Moreover, studies focused on traditional resource use by village communities such as tree planting, ownership of tree and forestry products and marketing hereof. These studies were particularly important for the restoration of degraded savannah environments in order to meet the specific needs of village communities without violating cultural values.

Environmental education on the importance of conservation and involving local people was considered essential for the success of the project. The project's main counterpart institution, the Environmental Protection Agency (EPA) of Ghana, carried out multi-layered education programmes: for example, seminars were organised on the control and prevention of bush-fires which could seriously affect the sacred groves, on the establishment of shelter belts around the groves, and women were trained in tree planting.

As it would lead to far to mention all project results in this overview, only a few will be briefly explained as follows:

One of the working hypotheses had been that the biodiversity within the sacred grove would be much higher than in the adjoining non-sacred areas. However, this was only half true. In terms of animal species diversity, birds, reptiles and mammals were more abundant within the sacred groves than outside the sacred groves. This was not a surprising result as the sacred sites also function as wildlife sanctuaries in which hunting is outright prohibited and trespassing of this customary law is penalized by the custodian of the sacred grove. An antelope, for example, can be hunted outside the grove, but as it enters the sacred grove, hunting has to stop. However, as regards plant species, a higher species diversity was found at the edges of the sacred groves than within the sacred sites. We assume that the edges of the sacred groves function like ecotones where two different environmental settings meet: an ecosystem with a closed canopy cover (sacred grove), and a human-impacted ecosystem where bush fallow or agriculture occurs. Hence, the differing light conditions at the edges of the sacred groves gives rise to a more heterogenous plant diversity than within the groves. It may also be assumed that the sacred groves in this savannah environment are dry forests in their climax or sub-climax stage which are less species rich than groves with secondary undergrowth.

Research on the cultural aspects and significance of the sacred sites also provided fascinating results: Through interviews with the village elders and extrapolation of historic events, it can be assumed that some of the sacred groves are over 300 years old. They originated either as the abodes of a god or several gods. The three selected groves were the respective abodes of a python god, a leopard god and a monkey god; they can command plenty or lean harvests. Other sacred groves in the study area served and still serve as burial grounds of ancestors and have become taboo over time. The power of a chief is intrinsically linked with his function as supreme custodian of a sacred grove. No matter whether the chief is a practising Muslim or Christian, his power over the community derives from his role as protector of the sacred grove. Should he relinquish this function, his power as chief would be forfeited.

The taboos and obligations, i.e. the "do's" and "don'ts", vary from one sacred site to the other, but there are also several common features. For instance creating shelter belts around the groves through communal labour is an obligation to everybody in the village community. The strict observance or adherence of the rules associated with the sacred groves is considered important and cannot be compromised.

However, as culture is dynamic, also belief systems can change over time, and many young people wish to extend their agricultural lands - even if this extension would feed into the sacred grove. The project, therefore, re-oriented its activities with regard to the rehabilitation of degraded lands around the sacred groves using agro-forestry methods. These permitted cash-crop production (e.g. cashew nuts, mango etc.), and provided an economic income to local people, especially women and young men. At the same time the restoration of a vegetation cover in particularly degraded areas was ensured. The establishment of woodlots and fodder banks were additional means to create a "buffer zone" around the sacred groves which in turn reduce the pressure on the sacred site itself. Figure 1 shows schematically two different situations: in situation (a) a large pressure on the sacred site prevails to use the area for economic purposes. In situation (b) a buffer zone has been created around the sacred site. This buffer zone provides income benefits for people (agro-forestry, woodlots, fodder banks, cash crops etc.) so that the pressure on the sacred site is reduced.

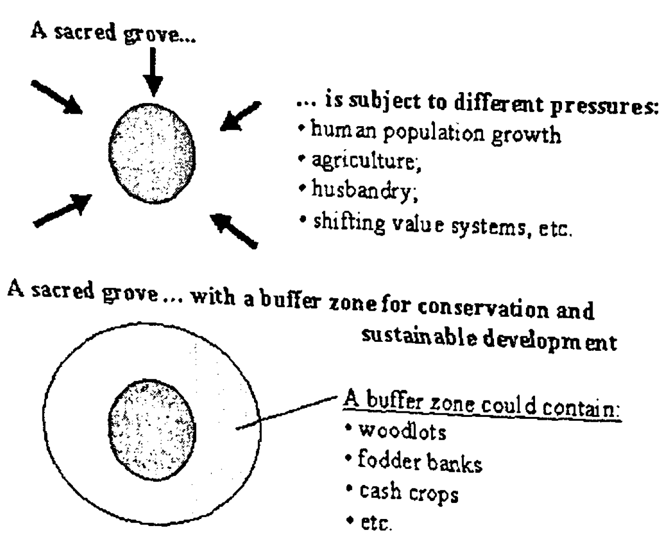

Figure 1. Sacred groves and buffer zones

The World Network of Biosphere Reserves

The CIPSEG Project in Ghana also illustrates that the MAB Programme is increasingly addressing the central question of the Rio Conference in 1992: how can we conserve the environment (e.g. drylands) while at the same time ensuring sustainable development for people? How can we reconcile conservation of biological resources with their sustainable use? One answer to this question could be the approach adopted by UNESCO within its "World Network of Biosphere Reserves". Biosphere reserves combine environmental conservation with economic activities based on spatial analysis and scientific land use and land management studies.

According to their shortest definition, biosphere reserves are areas of terrestrial and coastal ecosystems which are internationally recognized within the framework of UNESCO's Man and the Biosphere (MAB) Programme. Collectively, they constitute a World Network. They are nominated by national governments and must meet a set of criteria and adhere to a set of conditions before being admitted into the World Network. Each Biosphere Reserve is intended to fulfill three basic functions, which are complementary and mutually reinforcing:

- a *conservation* function - to contribute to the conservation of landscapes, ecosystems, species and genetic variation;
- a *development* function - to foster economic and human development which is socio-culturally and ecologically sustainable;
- a *logistic* function - to provide support for research, monitoring, education and information exchange related to local, national and global issues of conservation and development.

To carry out the complementary activities of nature conservation and use of natural resources, biosphere reserves are organized into three interrelated zones, known as the core area, the buffer zone and the transition area (please see Figure 2).

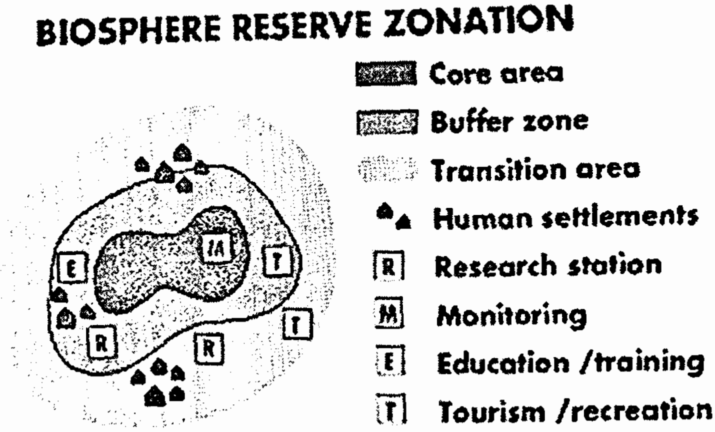

Figure 2. Schematic zonation of a biosphere reserve

The *core area* needs to be legally established and give long-term protection to the landscape, ecosystem and species it contains. It should be sufficiently large to meet these conservation objectives. As nature is rarely uniform and as historical land-use constraints exist in many parts of the world, there may be several core areas in a single biosphere reserve to ensure a representative coverage of the mosaic of ecological systems. Normally, the core area is not subject to human activity, except research and monitoring and, as the case may be, to traditional extractive uses by local communities.

A *buffer zone* (or zones) which is clearly delineated and which surrounds or is contiguous to the core area. Activities are organized here so that they do not hinder the conservation objectives of the core area but rather help to protect it, hence the idea of "buffering". It can be an area for experimental research, for example to discover ways to manage natural vegetation, croplands, forests, fisheries, to enhance high quality production while conserving natural processes and biodiversity, including soil resources, to the maximum extent possible. In a similar manner, experiments can be carried out in the buffer zone to explore how to rehabilitate degraded areas.

An *outer transition area*, or area of co-operation extending outwards, which may contain a variety of agricultural activities, human settlements and other uses. It is here that the local communities, conservation agencies, scientists, civil associations, cultural groups, private enterprises and other stakeholders must agree to work together to manage and sustainably develop the area's resources for the benefit of the people who live there. Given the role that biosphere reserves should play in promoting the sustainable management of the natural resources of the region in which they lie, the transition area is of great economic and social significance for regional development.

Although presented schematically as a series of concentric rings, the three zones are usually implemented in many different ways to accommodate local geographic conditions and constraints. This flexibility allows for creativity and adaptability, and is one of the greatest strengths of the concept.

The World Network is formally recognized by UNESCO's 188 Member States. To date (October 2001), there were 411 biosphere reserves in 94 countries (for the locations of each individual biosphere reserve, years of inscription, site descriptions and contact persons in charge of biosphere reserves, see the URL address http://unesco.org/mab/wnbr.htm).

While there is a strong concentration of biosphere reserves in the humid tropical forest zones, mountain ecosystems and temperate zones, fewer biosphere reserves exist in the world's drylands. However, some biosphere reserves have been nominated in the arid and semi-arid areas, such as for example the Bogeda or Xilin Gol biosphere reserves in the People's Republic of China, the Great Gobi Biosphere Reserve in Mongolia or the Wadi Dana Biosphere Reserve in Jordan. According to a decision by the MAB International Coordinating Council at its session in November 2000, the rehabilitation of degraded drylands using biosphere reserves is a new MAB research programme that is now being developed for the next few years. In essence, the programme would compare the relatively undisturbed core areas of biosphere reserves with the economically used transition areas for rehabilitation purposes. Putting a transect through the different zones of biosphere reserves, varying degrees of environmental conservation or inversely, environmental degradation, can be exemplified (please see Figure 3).

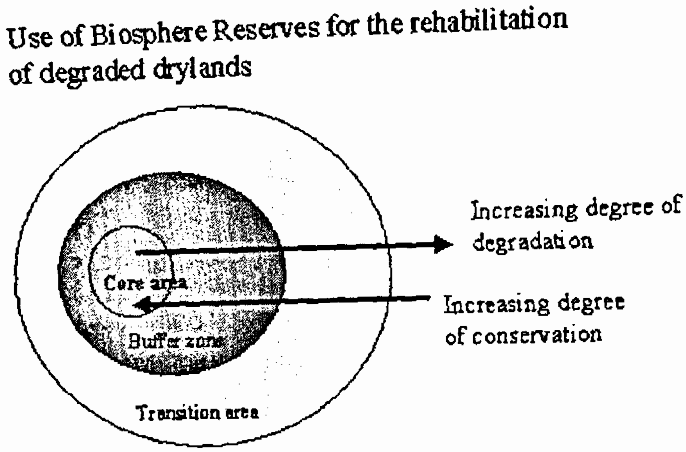

Figure 3. Transects through a biosphere reserve

Can the core areas be considered as reference sites of potential natural vegetation of the larger environment? Can the gene-pool of biosphere reserves be used for the restoration of stressed or degraded drylands? Should economic factors (e.g. the use of cash crops) be taken into consideration in restoration activities, or are environmental considerations (e.g. species diversity, rare species without economic "value") more important in dryland rehabilitation? Or would a mixture of economically viable zones (cash crops) with ecologically valuable zones be a preferred solution in the world's drylands? A planned UNESCO-MAB "International workshop on desertification: rehabilitation of degraded drylands and biosphere reserves" will try to seek answers to these and other related questions.

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4

Pioneers of Desert Studies in China and Japan - A Japanese Geographer's View

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Historical Development of the Chinese Desert Studies

Since my first official visit to China through the invitation of the Chinese Academy of Sciences in collaboration with the Japanese Association for the Advancement of Science in 1981, I have visited Chinese deserts more than ten times. During these visits, I appreciated very much the friendship of my Chinese colleagues including desert inhabitants and learned a lot from their experiences, progress and development of desert-related studies in China. In my personal experience and observation, the origins of scientific desert studies in China had already taken hold during the Sino-Japanese war. This was done under the leadership of eminent Chinese scientists such as Chu Kochen who was an distinguished climatologist, earth scientist, humanist and a man of culture. Through his original scientific research and diaries published after his death, we can remember his prominent leadership as one of the Zhejiang University founders and as vice-president of the Chinese Academy of Science (CAS). Prof. Kuo Mojo was the CAS president at that time, and was also a distinguished historian who had many academic and personal contacts with Japanese people. Chu was one of the most referenced scientists in the field of desert-related studies. However most important contributions to the Chinese Academia may be his leadership as a professor who educated his fellows at the University. Huang Bingwei and Zhao Songqiao were among his best students. Furthermore, although he passed away in 1995, Zhao left several excellent students of desert studies such as Zhu Zhenda and Xia Xuncheng who took initiatives on desert studies based in the CAS.

It is understandable that during the first ten years after the establishment of the Peoples Republic of China in 1949, Chinese scholars met various challenges and difficulties that had to be overcame. After the 1950's, Chinese researchers had already started desert study groups. We may mention among these some distinguished geographers such as Huang Bingwei and Zhao Songqiao. A key characteristic of the Chinese desert studies at that time was that these were meant not only for pure scientific purposes but also played an important role in the regional development of desert regions in China (for example, construction of the Taklimakan desert highway for the development of hydrocarbon resources, afforestation in degraded lands, etc.). In addition, we should appreciate the remarkable development in the use of GIS using remote sensing techniques in the more recent times.

Japan's Research Contributions to Desert Studies

In contrast to the Chinese researchers, Japanese scientists in this field have a major handicap in undertaking field studies because of lack of deserts in Japan. Nevertheless, Japanese people have a keen interest in the desert landscape and civilization through classical Chinese texts including history, literature, geography or reports of scientific missions. The older generation of Japanese who have got education before 1945 might know the poems of T'ang, Sung dynasties or even they made poems in hantsu (Chinese character). Generally speaking, it might be observed as a bit of nostalgic approach. On the other hand, Japanese scientists' involvement in desert research in China or adjacent regions might be influenced by Western scientists or geographers such as Ferdinand von Richthofen (1833-1905), Sven Hedin(1865-1952), Grorge B. Cressey (1896-1963), and John Lossing Buck(1890-1975). Most of their work was translated into Japanese for the general public and the interim government's use.

Opportunities for Japanese to undertake field studies in Chinese deserts were restricted because of Japanese military invasion especially after 1930's. Actually those research studies included some kind of military geography during this epoch, i.e. series of regional geography of inland China used mainly for military operation. Notwithstanding that, I do remember the academic atmosphere among scholars who were interested in China was very calm and they were working through narrow but direct or indirect networks with Chinese scientists. After 1941, it was almost difficult to obtain new books printed outside Japan but we could buy precious reprints of western scholars contributions on Chinese studies including fundamental classics such as the "Bibliotheca Sinica" (Henri Cordier), and basic text books in Chinese on history, geography and literature printed in China.

In spite of the existence of tensions between the two countries, very fundamental works on archaeological sites including restoration of Datung Buddhistic stone caves were achieved by Seiichi Mizuno and his colleagues in collaboration with Chinese scientists. The voluminous scientific reports published just before the Peace Treaty at San Francisco (1952) was shown by Japanese representative Shigeru Yoshida, Prime Minister of Japan, to all delegations as a testimony of Japanese academic and peaceful contribution to the Chinese people even under unfortunate wartime conditions. Actually, it was practically impossible for Japanese scientists to work in a friendly atmosphere in collaboration with Chinese scientists between the 1930's and 1960's. As a young geography student of Tokyo Imperial University, I visited Manzhou-guo in 1944 for the study of settlement geography and Manzhou and Mongols languages. This study was sponsored by Tokyo Imperial University, however most of persons involved were Japanese, except few Russians researchers working in Harbin, and also Manzhou farmers and Mongol nomads encountered during my field survey. Even under those difficult conditions, we had contributions from Japanese scientists such as Fumio Tada (Inner Mongolia), Kinji Imanishi (Inner Mongolia and Manchuria), Mutsumi Hoyanagi (Northern China). As another example, Hoyanagi's work on environmental change of the silk road who published one of the best books that represent a combination of Chinese, Western and Japanese researches. And also, Imanishi left behind a legacy of several students who became distinguished scholars at the Japanese Academia in the field of ecology, biology, geography, anthropology and geology of Eurasia such as Tadao Umesao and Tatsuo Kira.

UNU's Role in Sino-Japanese Collaboration

The United Nations University (UNU) was founded in 1975 and started as a kind of a "think-tank" organization for the United Nations including networks of international academic institutions and individual scientists. One of the initial research programs was focused on natural resources management. In 1979, the United Nations University, through the initiative of Walther Manshard (Vice-rector and General secretary of International Geographical Union), invited a large mission of geographers headed by Wu Chuanjun, whose group had a tremendous impact on the Japanese academia including desert studies. They attended the Autumn meeting of the Japanese Association of Geographers in Kanazawa and established new friendships with many Japanese geographers. After 1979, UNU has continued various collaborations with the Chinese Academy of Sciences and the Chinese Academy of Social

Sciences. For example, Wu Chuangjun and myself were members of the advisory committee on natural resources program which included the monitoring mission for the mega-engineering to build canals between the Yellow River and Yangtse river. On the occasion of the 24th the International Geographical Congress (1980) held in Japan, Zhao Songqiao was invited to report recent trends of desert studies in China and he showed us many maps and photos unknown to foreigners. Therefore, Japanese as well as foreign scholars had the opportunity to view the latest information on the Chinese deserts. This symposium was one of the research programs of the UNU coordinated by Jack Mabbut and myself.

Contemporary Collaboration between Chinese and Japanese Researchers

Since the Japanese government signed the historical Sino-Japanese Peace Treaty in 1972, official exchange of scientists has become easier and especially from the 1980s' up to the present time, the so-called Sino-Japanese collaborative research has been consequently promoted quite extensively and intensively. Executive agencies for those collaborations are not only ministries of Education, Agriculture, Industry and Trade or Agencies of Science and Technology, or Environment but also universities which played a key roles for basic researches. As the counterpart to the CAS on the Chinese side, the Japanese contribution spanned many Departments equivalent to Japanese ministries and agencies that had bilateral relations and played a very important role.

Among the key topics for this Sino-Japanese research collaboration, we may mention "Mechanism of Desertification", "Advanced and Traditional Technologies in Desert Development and Desert Civilization." In 1990, the Japanese scientists established the Japanese Association of Arid Land Studies and we were very pleased to receive a warm message from the Chinese Academia (message of Xia Xuncheng, Urumqi) on the occasion of the inauguration ceremony held on May 18, 1990. The Association's official journal "Journal of Arid Land Studies" often included contributions from Chinese scientists and even published a special issue on Taklimakan. Our association may constitute a unique organization among similar associations in the world, because the mandate covers not only natural science but also social sciences and humanities. Membership is open to anyone or any nationality who are interested in arid land studies. The Desert Technology Division of the Association had already organized six international symposia, and the 6th meeting was held in Urumqi in Collaboration with the Chinese Academy of Sciences, Xinjiang Branch (2000). Thanks to the network of about 500 members, we welcomed many Chinese professors and young scientists of Japanese Institutions. We are very happy to have young Chinese desert scientists who earned their Ph.D. degree from Japanese universities and are now working in Japan as Professors in universities and researchers at related institutions.

Concerning the UN Convention to Combat Desertification, Japan and China have already ratified it, and work together in several fields. In particular, the Thematic Programme Network (TPN) 1 which is now coordinated by the Department of Forestry in Beijing in close collaboration with its Japanese counterparts. Beside this international corporation, bilateral corporation between the two governments is going to start and the theme would be most probably on "Mechanism of dust storm and its influence on human life".

In addition to scientific channels, we may have to mention the goodwill activities of more than a dozen Japanese NGO groups undertaken by grassroots basis. Among these NGO leaders we may find a former professor of agronomy who is thinking to return his moral debt to Chinese people especially the students. He is a middle-aged engineer who is seeking to establish the so-called "bio-village" in sandy desert area. Similarly, another farmer retired chief of the village is now willing to spend the rest of his life for Chinese farmers in dry areas. They usually receive financial support through volunteer donations or small subsidizes from government or private funding agencies. These groups are working for the "rehabilitation of degraded lands in dry areas" or "greening of deserts" (though the term looks like a mix of Japanese and English and sometimes brings us some confusion about the concept). Hence, we should be patient to see and enjoy the would-be positive achievements of those kinds of grassroots collaboration among peoples at least on a five years time span.

Conclusions – An Outlook Towards the Future

It is impossible to refer to all names or works of Chinese and Japanese desert scientists in this short paper. However, we, Japanese scientists, owe so much to Chinese scientists from the past. Japanese scientists have now more chances to work peacefully together with Chinese scientists supported by various organs in and outside Japan.

As a conclusion to this paper, I would like to mention that the UNU can be one of the best coordinators not only for Chinese or Japanese academia but also any other national or international academia. The standpoint of the University's academic freedom under the United Nations system can facilitate activities among the various concerned stakeholders. Concerning desert studies, the UNU is now already working together with other interesting agencies including the CAS, UNESCO, the International Center for Agricultural Researches for the Dry Areas (ICARDA), and other important institutions around the world.

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5

Sustainable Development and Desertification Control of the Oases in the Heihe River Drainage

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Introduction

Heihe River originates from Qilian Mountain, and has the water of glacier melted and precipitation in mountain as its source. It is the largest river in land of the Hexi area as long as 821 km, and flows through Qilian county of Qinghai province, the Hexi corridor of Gansu province and Ejina Qi of Inner Mongolia Autonomous. There are almost 200 million people living close to the river.

According to the survey data in 1980's and 1990's, the net utilization rate of the river water was 48.96% and 57.4% respectively, over the safe standard (40%). During the end of the 20th century, the lakes and river branches disappeared in the lower reaches of the river and the valley forest decreased by the downward of the river in Ejina Qi. The conflict is the allocation of the water between upper area and downward area, of the economical development and the ecological security.

The river in land originates from mountain and flows down to the desert, the oases formed along the river, that should be treated as the whole and the one system. Water resource is limited in the arid area, more consumed water at upper reaches of the river means that the oases shrink or even die away at the downward of the drainage area. So the mountain, oases and the desert linked by the river is one eco-functional system.

Background

Shortage of water and unreasonable utilization of the limited available water is the main case of the desertification development in the Heihe River area. In the upper reach of the river, the grassland is seriously degenerated due to overgrazing in the sub-high and middle Qilan mountain and the function of water conservation is quite weak. In the middle drainage basin, there is the largest oasis of the Hexi corridor. The over-exploitation and expansion of the oasis, its flood irrigation and increased population have caused breaks in the flow of the Heihe river. As the water utilization is increasing, the time of these break flows of Heihe river is becoming longer. In the lower reach, the bank forest in the Ejina oasis grows weakly and lot of trees and shrubs have died because not enough water is available. Water shortage are leading to the dwindling or even disappearance of oases in lower reach area of Heihe River, the drying up of terminal lakes, extending of desert, increasing in dust storm frequency and aggravation of desertification.

The oases developed in the Heihe River in Hexi Corridor of Gansu province, including the largest continuous oasis in Noth-Western China, are the important commercial grain production basin of the Gansu Province. Grain-dominated cultural structure and irrational flooding irrigation exacerbate the contradiction of water shortage. Owing to its unique geographical position and expanding irrigation farmland and construction development, there are some environmental and construction problems that need to be solved urgently.

Hexi Corridor is surrounded by large Badain Jaran Deserts and Tengger Desert in the north. The total desert area of 18772 km^2, accounts for 8.78% of the total Hexi area. Similarly, part of the Gobi desert also is included here with an area of 67699.28 km^2, or 31.66% of the total Hexi area. The oasis area in the Hexi Corridor is only 10947.1 km^2, 5.12% of its total. The degradation of natural vegetation such as shrubs and grassland around the oasis has led to a loss of the protective screen to the oasis. It is not surprising that desertification occurs around the oasis and sand dunes frequently break into at the margin of the oasis. Lightly, moderately and severely desertified land areas at the margin of the oasis are 560 km^2, 2272 km^2, and 1824 km^2, respectively.

The oases in the middle region of Heihe River drainage play a very important role for both environmental security and economical development of the river drainage basin. Because the oases located in middle reaches of the river are the main water consumption areas and the core of economic activity, people tend to converge to the Hexi corridor of Gansu province. There are 6 counties named Shandan, Minle, Zhangye, Linze, Gaotai and Jinta, the population and the irrigation farmland is 93.16% and 96.23% of the whole drainage basin respectively (Table 1). The new water allocation scheme of the Heihe River has put into operation by national hydraulic department, the amount of water utilization in the midstream region will be limited. The agriculture productive needs water save techniques and management system.

To solve the problem, the Chinese Academy of Sciences funding a project: "Demonstration of Water-Ecology-Economy Systems Integrate Management in Heihe River Drainage basin". The project runs from 2000 to 2004. Three counties were choose as the study areas: Sunan county located in the upper reaches of the Heihe river, Linze county located in the middle reach and the Ejina county located in the lower reaches of the river.

The project includes 4 subprojects:

1. Water and soil conservation in Qilian Mountainous grassland in Suna County; upper reaches of Heihe River
2. Water conservation management and techniques of agriculture system, low water consumption protective system of oasis in Linze County, middle reaches of Heihe River
3. Rehabilitation of degraded environment in Ejina Region of lower reaches of Heihe River
4. Models of ecological security and water resource optimizing allocation in Heihe River drainage basin

The objectives of the project include:

- Rehabilitation the protective system of the oasis and fixing the sand dunes around and inside the oasis.
- Find the optimized applications oriented for sustainable development and ease-of-use by farmers for conserving the irrigation water and increase the income of farmers.
- Establish the harmonious relationship between the human being and the environment, while maintaining sustainable economic development and environment security.

Conditions in the Middle Reaches of the Heihe River Demonstration Area

The demonstration county of Linze, has 144.7 thousand people, 22839.8 ha irrigation farmland, about 10% of the all Heihe River drainage basin. It is a dry temperate continental climate with long sunshine hours, intense solar radiation, sharp temperature difference between day and night, sparse but concentrated precipitation and high evaporation. Annual sunshine hours is about 3053.9 h, annual total radiation 146.2k·cal·cm^{-1}, annual mean air temperature 7.7°C, ≥0°C cumulative temperature 3544.6°C, and ≥10°C cumulative temperature is 3092.4°C. Frost-free period is 153 days. The annual mean precipitation is 117.0 mm, and annual evaporation 2337.6mm. Annual mean wind velocity is 3.2 m/s and the number of gale days (>17m/s) is 15 days dominated by northwestern wind. Climatic disasters for agriculture are drought, frost, gale, and dry - hot wind.

The oases have expanded almost double in area and population compared to 1950's due to immigrant and population increase. As a result, the original margin of the oasis has become an immigrant village with imperfect protective systems. Except the land reclamation for increasing people's income, livestock production has become one of the important income sources for farmers although artificial grassland area is small. Grazing results in serious degradation of natural vegetation. The destruction of natural vegetation caused by grazing and for people cooking and warm, constitutes an obvious problem to local eco-environmental construction and socioeconomic development.

The oases are under the desertification threats through three main mechanisms:

1. *Sand dunes breaking into the margin of the oasis*: Surrounded by desert, the oases in Hexi corridor region are always under the threat of desert encroachment. A shelter system is the key element to protect oasis from being encroached by desert and eroded by wind. Nevertheless, some problems are still present in the existing protective system. Protective systems that were established 20 years ago mainly consist of single and aged poplar trees with high water consumption and face the threat of yellow spot beetle. Therefore, there is an urgent need to rectify this. Some of newly reclaimed wasteland is still encroached by sand dunes, hence comprehensive control measures must be taken to ensure stable agricultural. Sand-fixing vegetation dominated by *Haloxylon ammodendron* can not regenerate naturally and shows symptoms of degradation. Crest sections of fixed dunes reactivated and wind erosion occurred.

2. *Wind erosion inside the oasis.* Some fixed dunes were reactivated due to vegetation destruction, and wind erosion and blown sand spread occurred inside the oasis. Plant cover shortage of arable land in windy season is another case of land wind erosion.

3. *Frequent sand and dust storms.* Sand dust storms occurred frequently in the area and often cause severe damages. What is noteworthy is that in recent years dust storm frequency tended to increase and their also appeared to increase. For example, the catastrophic dust storm event occurred in the May of 1993 and Gansu province, Xinjiang, Ningxia and Inner Mongolia Autonomies were affected and resulted in an economic loss of 64.39 million Yuan. The sand dust storm occurred on the first day of 2001, even impacted the half part of China.

Advantages of the demonstration in Linze are:

1. Because it is situated in the desert region, the demonstration plot has a large light and heat production potential.
2. Grain production in the region is self-sufficient or even surplus, hence part of croplands can be reverted to grassland and other economic crop lands.
3. The demonstration plot has been included in the state key sand control region. As early as the late 1970's and the early 1980's, a 10-50 m wide sand-break forest has been established along the main canal at the margin of the oasis.
4. In the meantime various sand-fixing plants were also planted on the sand dunes at the margin of the oasis and in interdune depressions. Sand dune fields around the protective forest were closed to facilitate grass growth and to prevent the encroachment of shifting sand. As a result shifting sand area has decreased from original 54.6% to present 9.4%, wind eroded cropland area has decreased from original 17.8% to present 0.4%, cropland and wood land area has increased from original 6.1% to present 43% and per capita income increased by 153%.

The Approaches for Sustainable Development in Oases of the Heihe River Middle Reaches

According to the physical and socioeconomic conditions and environmental issues in the region, we designed the sub-project according to the following principle: Supplement the protective system as the main body, taking water-conservation as major approach, leading to a comprehensive utilization and sustainable development approach in both of environmental and economic spheres.

1. Change the agricultural strategy, increase the amount of water-conserving crops instead of the traditional wheat and corn production. Sustainable development mainly manifests that integrated measures are adopted to improve agricultural production conditions of the demonstration site. The water efficiency and farmer's income in the oasis is much lower, utilizing each m^3 of water resulting in crop values of less than 0.1 US$ (please see Table 2). Readjusting the crop structure and selecting water-conserving crop varieties will is a major improvement and it will be supplemented by introducing somewhat expensive water-conserving irrigation equipment on a secondary basis.
2. Enhancing economic efficiency of per m^3 of water so that the farmers' income will increase even if the amount of water utilization will not increase, or farmers' income will not decrease under the condition that the amount of water utilization reduces. According to present grain prices and price prediction after China enters WTO, the economic efficiency of oasis agriculture dominated by grain production would be maintained at present low level. Under the precondition of ensuring grain security, crop structure should be modified so that production cost and water consumption reduce and the farmers' income increases.
3. Some low water-consumption and low-input forages and medical plants are planted on the reverted croplands to improve economic efficiency of per m^3 water.
4. Tests of water and fertilizer management patterns to get optimal grain and forage yields in the field conditions are also included in this design. Cultivation measures, mechanical measures and biological measure and their

combination will be adopted simultaneously to achieve optimal efficiency.

5. Stabilizing the shifting sand dunes by using straw square and biological measures is also an important aspect. Some of the original sand-break forest stand due to human activities including grazing, desert vegetation dominated by *Nitraria tongutorum* has been destroyed and disturbed soil surface has become loose leading to wind season. Enclosing the disturbed land to prohibit grazing so that natural vegetation restore and wind erosion reduces.
6. Comprehensive sand control measures including stabilization, blockade and mulching techniques are being adopted to control shifting sand. In the meantime, irrigation canal system is being built in inter-dune depressions to irrigate the sand-fixing plantation. Patches of shifting sand on the *Haloxylon ammodendron*-dominated fixed dune appeared due to poor natural regeneration and human destruction. Numerous species are concentrated on inter dune depressions. and pond side.
7. Establish mixed water-conservation and insect-resistant wind-break forest system is yet another aspect. Because the poplar trees in the existing protective system have high water consumption and are under the threat of westward migrating yellow spot beetles, some patchy forests grow rather poor due to high density. Triploid *populus tomentosa*, and *populus nigra* are selected to replace the original belt, and intermediate cutting is also adopted to thin the patchy forests.

Table 1. Distribution of population and irrigation land of the Heihe River Drainage Basin

Area in the river drainage	County	Population (Thousands)	Percent (%)	Irrigation farmland (ha)	Percent (%)
Upper	Qilian	43.7	3.02	2966.70	1.30
	Suna	39.4	2.72	4159.40	1.82
Middle	Shandan	202.1	13.95	30798.47	13.49
	Minle	238.2	16.44	50886.27	22.29
	Zhangye	469.0	32.36	69216.13	30.31
	Linze	144.7	9.99	22839.80	10.00
	Gaotai	159.7	11.02	22992.13	10.07
	Jinta	136.4	9.41	22992.13	10.07
lower	Ejina	15.9	1.1	1480.00	0.65
Total		1449.1	100	228331.00	100

Table 2. Cultural input efficiency and water consumption in the oases of middle reaches of the Heihe River

Crops		Wheat	Corn	Cotton	Strip field	Oil-bearing crop	Beet	Greenhouse veg.	Field veg.	tomatoes	Alfalfa
Actual plant area(mu)		1.0	1.0	1.0	1.0	1.0	1.0	0.7	1.0	1.0	1.0
Mean yield	kg/mu	380	546	46	800	130	1550	3000	3200	2250	920
In-come	Yuan	418	437	552	720	429	403	4500	1280	1125	414
Input (Yuan)	Seed	58	21	28	80	14	24	90	35	110	5
	PVC film		60	60	40			420	50	90	
	Fertilizer	106	130	105	220	93	120	350	230	330	80
	Labor force	42	49	35	63	49	49	28	63	42	35
	Tax paid	120	80	160	200	90	60	900	320	260	60
	Others	40	40		40	40	40	120	40	40	40
	Total	366	380	388	643	286	293	1908	738	872	220
Net income	Yuan	52	57	164	77	143	110	2592	542	253	194
Water consumption	m^3/Mu	600	700	500	900	700	700	400	900	600	500

Note: 1 Mu is equal to 666 m^2.
Hexi corridor region has about 100,000 kg of ovestocked grain.
Per capita grain in Zhangye region: 822.28kg
wheat prices: 1.04 Yuan in zhanye;
0.80 Yuan/kg in Shaanxi and Henan.

6

Mismanagement of Land Resources and Land Degradation in Horqin Sandy Land

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Introduction

Desertification is a process of land degradation. Due to the adverse climate and human activities, desertification is expanding at an ever-increasing rate in China: 1560km^2 per year in 1950's and 1960's, 2100 km^2 in 1980's (Zhu Zhenda, 1994) and 2460 km^2 in 1990's (Wang Tao, 1999), respectively. As a result, the total desertified land areas reached at 2.7 million km^2 in the year 2000, accounting for one third of the total land areas of the nation. There are about 851 counties suffering from desertification. Since late 1950's, people in the northeast, north and northwest parts of China started to control desertification to protect their land, livestock and the ambient environment. The government also initiated the well-known greening project-'The Sanbei Shelterbelt System'. 'The Sanbei' is referred to as the Northeast, North and Northwest parts of China and stretches nearly 4000 km from Xinjiang in west China to Heilongjiang in east China. After nearly half a century, great achievements have been made in some sites, but as a whole, desertification is still expanding and large areas of cropland and grassland was engulfed by sand. In recent years, the impact of desertification was intensified by frequent sand and dust storms, which were attacking the infrastructure, lives and lives' facilities, not only in the places that the storms took place, but even places far away.

Drying-up of rivers, lowered underground water table and shrinkage of water bodies were getting more and more common in the west, north and northeast part of China. These changes were recognized as a result of the mismanagement of land resources and the indicators of the increased fragility of ecosystems. It is foreseeable that the trend of increased fragility would be kept on with the increasing population and ever-increasing demand for food and income.

Horqin Sandy Land is located in the eastern part of the Agro-pastoral transitional zone of China. It also belongs to the interlocked area between the semi-arid and semi-humid areas, with a monthly mean air temperature of 22°C in July and −16 °C in January. The long-term annual mean precipitation is 368 mm and the potential evaporation 1900 mm. It was once one of best grasslands in China. Horqin Sandy Land, therefore, has a better natural condition than other sandy lands. Since the beginning of last century, with the increase of population, grassland has been cultivated, trees cut, water resource exploited prodigally. Consequently, desertification expanded very fast. In middle of 1980's, the total area reached at 43,200 km^2. In the past 40 years, the local governments, masses and researchers have made great efforts in desertification control and met with successes, which was characterized with the increase of vegetation cover in many a places, but as a whole, the environment quality is not much improved; rivers were dried up, underground water table lowered and water bodies shrank.

Therefore, it is of great importance to discuss and evaluate the successes and failures in land management and find out the immediate causes of land degradation, and water and land resource deterioration in Horqin Sandy Land. This could provide references to land management in other part of the nation.

Mismanagement of Cropland

Mismanagement of land resources, such as over-cultivation, over-grazing, over-cutting and collection of fuelwood and medicine herbs, etc., had been discussed profoundly (Liu Xinmin, 1993; Zhu Zhenda, 1994, 1999). This article focuses only on the mismanagement of cropland, which is closely related to soil properties and water resources. In Horqin Sandy Land, cropland is generally composed of irrigated cropland located on lower land of various sizes, rainfed cropland on sand with different slopes, and paddy field along in the two sides of river systems. With the application of well digging techniques and related equipment, and driven by increased demand of growing population and pusuing higher income, irrigated cropland was increased very fast in the past 50 years. As a result, the once relatively abundant water resource was overused.

Mismanagement of land in this area includes the improper choice of land, not leveled cropland and loss of soil organic matter (SOM) from cropland systems, etc. As mentioned above, irrigated cropland in this area was mainly distributed in the lower areas of well-textured and productive soil. Generally, this soil has eight layers, of which three are clay and five sandy. The three clay layers interlaid with the five sandy layers. The thickness of the three clay layers was 15cm, 18cm and at least more than 2cm, respectively (please see Table 1). The first clay layer, rightly under the ploughed layer ranging from 32cm to 47cm, together with the mould layer ranging from 0 to 15cm and rich in soil organic matter, play an important role in water holding and nutrient supply. The averaged yield of this soil is 700-900kg/mu and the farmers treasure it as the 'life-saving land'. However, in order to increase the income, large area of fixed dunes were roughly leveled off and irrigated for grain production. This kind of land has poor structure and water and nutrient holding capacity. Measurement showed that about 20-30% of the irrigated water was leached through the transecting one meter deep in the soil. This kind of newly cultivated land was already nearly one fifth of the total irrigated cropland in this area.

Table 1. Profile of the irrigated cropland soil

Layer	Thickness cm	Description	Structure
1	0-15	Silt-fine root-SOM-high WHC	Single
2	15-32	Fine sand-less clay, poor WHC	Single
3	32-47	clay-root-porous, high WHC	Agglomerate
4	47-52	Silt-poor WHC	Single
5	52-70	Clay mixed with silt, moderate WHC	Agglomerate
6	70-87	Silt, no root, poor WHC	Single
7	87-98	Silt-no root, mottles, poor WHC	Single
8	98->100	Clay-porosity, good WHC	Agglomerate

WHC=Water holding capacity; SOM=Soil organic matter

Irrigated cropland with slopes or not well leveled off can greatly increase the consumption of water for irrigation. Measurement showed that irrigated cropland in Horqin Sandy Land has a slope of 1° and some patches with 2-3° as maximum. When the land is well leveled off, with a slope less than 1°, it needs about 50t of water to irrigate one mu (one mu equal to one fifteenth ha). If the slope increased to 2°, the amount of water increased to 70-80t per mu and even to the maximum of 100t. The unleveled cropland could not be well-irrigated and also has increased irrigation times. For example, maize, the dominant crop in this region, generally, needs to be irrigated for three times. It needs to be irrigated one more time when the cropland was not well leveled.

Drought stress could also greatly increase the water amount for irrigation. Taking the maize as an example again, when hit by drought, maize need to be irrigated for at least five times. That is to say that in a normal year, the total annual water consumption of maize in the well-leveled land is around 150t, but this figure could be increased to 280-320t in the unleveled cropland and dry year(s).

Table2. Profile of the rainfed cropland soil

Layer	Thickness cm	Description	Structure
1	0-11	Silt-fine root-SOM, high WHC	Single
2	11-23	Fine silt-root, poor WHC	Single
3	23-31	Clay mixed with sand-root, high WHC	Agglomerate
4	31-42	Fine sand-no root-moderate WHC	Single
5	42-52	Silt-course root-poor WHC	Single
6	52-66	Silt-no root-poor WHC	Single
7	66-87	Sand-no root-poor WHC	Single
8	87-100	Silt-no root-poor WHC,	Single

WHC=Water holding capacity; SOM=Soil organic matter

Cultivation on sloping sandy land (it is rainfed cropland on fixed and semi-fixed grassland) not only directly destructed the vegetation and exposed the land to wind erosion after harvested, but frequently led to harvest failure. At first, this is closely related to the soil properties including slope. From Table 2, it is clear that although the slope sandy cropland has eight recognizable layers too, only one clay layer developed at the depth of 21-32 cm, the others are sand and silt.

This kind of profile indicates poor water holding and nutrient conservation capacities of the soil (Xubin, 1993). The averaged yield of soybean on this land is 80-100kg per mu, or no yield in dry year. The very reason for the farmers to cultivate on this land is the lower investment. Figure 1 showed the spatial distribution pattern of soil organic matter and nutrient contents versus the relative height of the rainfed cropland soil.

The changes of soil N and organic C in the range of 0-20cm were measured along a line from irrigated crop land in lower land to the rainfed cropland on shifting sand via a rainfed cropland on fixed sand. It is clear in figure 1 that, at the section of 0 to 2.5 on the X axel, the total soil N and organic C decreased with the increase of height. This is mainly due to the losses of nutrients and soil organic matter by water leakage. After point 2.5, the height was decreased by wind erosion, but almost no changes in the total N and organic C. This is due to severe soil erosion cutting deep into the pure sand of stable and lower N and C contents. Most of the rainfed cropland and some irrigated cropland sited on the slope sand with a range of slope from 1-5, some at 16 degree as the maximum of rainfed cropland in Horqin Sandy Land.

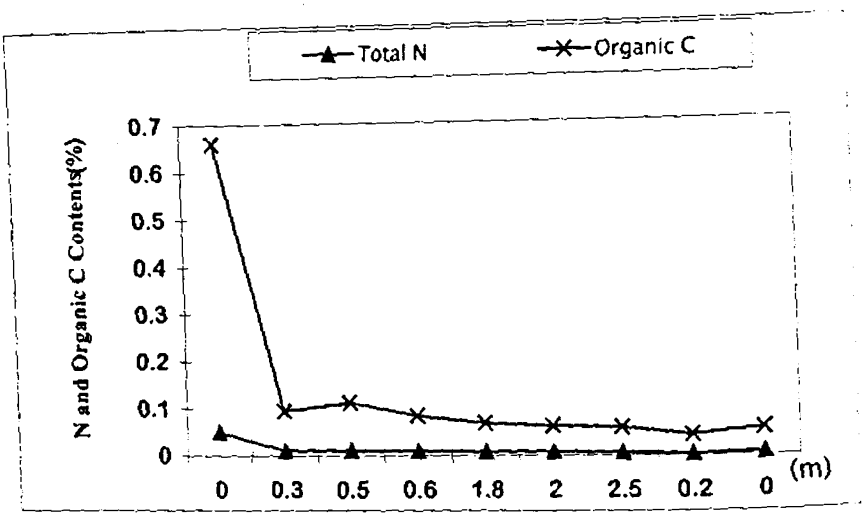

Figure 1. Curves of soil organic C and N vs. relative height of soil profile from irrigated cropland to rainfed cropland

It is noticeable that either the total soil N or organic C content decreased sharply when the height increased to 0.3m, at which irrigated cropland turned to fixed sand.

Timing of tillage is recognized as one of the factors leading to loss of soil organic matter. In Horqin Sandy Land, farmers usually harvest the crops and plough the land in the autumn. In addition to slope, this kind of soil management always exposed the land to wind action. Table 3 showed the changes of soil organic matter contents in three different managed croplands. It is clear that no-tillage (in autumn but right before seeding in the spring), compared to the irrigated and rainfed cropland ploughed in the autumn, could preserve a great amount of soil organic matter. When measured in the spring, the no-tillage soil had an organic matter content of 108.0kg/mu, while the irrigated and rainfed cropland soils had an organic matter content of 99kg/mu and 62kg/mu, respectively. The loss rate of SOM in rainfed cropland was 46kg/mu, nearly half of SOM in the no-tillage land.

Cropping on the rainfed cropland ploughed in the autumn created a condition for wind erosion.

Table 3. Changes of SOM contents of different croplands

Cropland	SOM (kg/mu)	SOM lost (kg/mu)	Notes
Irrigated	99.0	9.0	No slope
Rainfed	62.0	46.0	No slope
No tillage	108.0	0.0	Ploughed in Spring

SOM is the most important part of soil structure and nutrient. Loss of SOM is the most crucial process of land degradation. Therefore, restoration of degraded land is virtually a process of increase of SOM or reconstruction of SOM pool of the soil. Application of green manure and increasing mulch of crop residues are two effective approaches to improve soil structure and productivity (Zhao Xueyong, 1993).

Changes of Land use

Changes of land use are generally driven by the growing population, income pursuit, technology and land use policies (William, 1994). The temporal change of land use pattern in Naiman County was characterized with the increases of rainfed cropland, reached at its peak of 2,000,000ha in 1960, then decreased till the middle of 1990s, and then jumped up again. The increasing population and land use policy of 'the Great Leap' drove this increase before 1960. After 1960, with the development of digging well techniques and equipment, application of chemical fertilizer and introduction of hybridized varieties of maize, good harvest obtained on the irrigated cropland, then the rainfed cropland was reduced (Figure 2). In the period from 1949 to 1976, the averaged yield of maize on rainfed cropland was low, about 100 to 250kg per mu and this figure was increased to 700-850kg per mu in middle of 1980s.

In 1997, the government adopted the policy of 'no change of land use right for 30 years'; land was redistributed to the individual farmers and some farmers started to enlarge their rainfed cropland again. From figure 2, it is clear that the irrigated cropland was increased consistently while the paddy land kept unchanged until later 1980s. As stated above, paddy land mainly distributed along the river systems. Since the late 1980's and early 1990's, river systems were gradually dried up and left large area of river beaches without water. Most of these beaches now were cultivated into paddy land and some at high position were cropped with maize. This is the reason that paddy land increased since later 1980s.

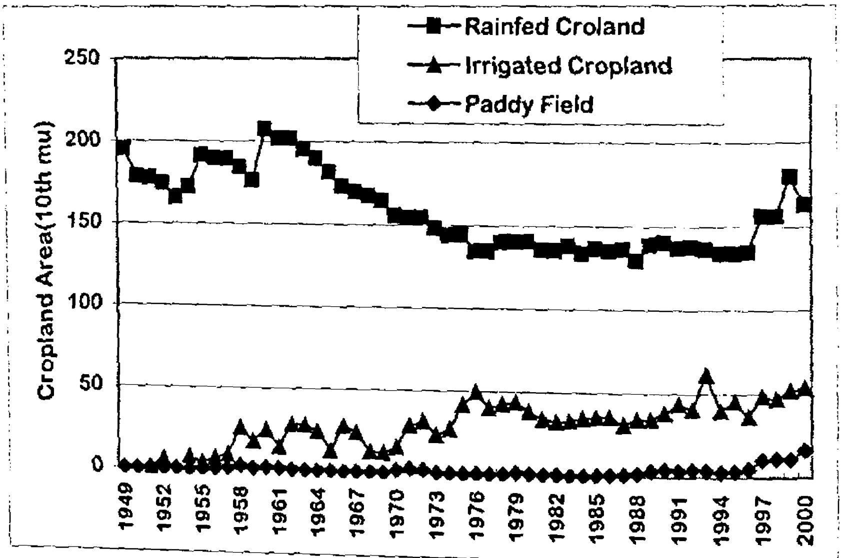

Figure 2. Changes of land uses in Naiman, Inner-Mongolia

In Horqin Sandy Land, food is not a problem for the farmers; thus, pursuing growing income mainly pushes the change of land use. Increase of rainfed cropland not only destroyed equal area of grassland, but also increased the consumption of underground water resource. Cultivation of river beaches has imposed severe impacts on the development of river systems, such as blockage of water flux during flood and consumption large amount of water in drought. Secondary salinization of the cultivated river beaches is a popular phenomenon in Horqin Sandy Land.

Ecological Impacts of Land Mismanagement in Horqin Sandy Land

As stated above, mismanagement of land resource has imposed severe impacts on the changes of the ecological processes, such as desertification and its control, underground water table change and changes of runoff and water bodies.

Desertification and Its Control in Horqin Sandy Land

Compared to other sandy lands, Horqin Sandy Land has a higher annual precipitation and it is moderately abundant in water resource. Therefore, there is the potential for natural restoration of vegetation. And thus revegetation, either naturally or artificially, was chosen as one of the prevailing measures for desertification control and vegetation coverage change was popularly cited as an important index to classification of desertification (Zhu Zhenda, 1994).

Based on the aerial photographs and satellite images of Naiman County located in the center of Horqin Sandy Land, analyses showed that from 1958 to 1998, the total area of fixed sand and semi-fixed sand was increased from 18118.2ha to 19293.5ha except for the decrease to 7319.5ha in 1974. The shifting sand was reduced from 15091.3ha to 11866.9ha and the semi-fixed sand increased from 5082.6ha to 11972.1ha. It is noticeable that the change of fixed dune area presented a decreasing trend (Figure 3). This is mainly due to the conversion of fixed sand into cropland (Liu Xinmin, 1993).

In Horqin Sandy Land, of course including Naiman County, most of the fixed sand region is gently fluctuated grassland and of high soil nutrient and SOM content. And more frequently, this land was firstly used as rainfed cropland and then leveled off and irrigated for cropping. From Figure 3, it is interesting to note that before 1974, the area, both of the fixed sand, semi-fixed sand decreased but the shifting sand. This was related to the change of land use. As shown above, rainfed cropland increased from 1949 and reached at the peak in 1960, and then decreased (Figure 2). Expansion of cropland was at the expense of fixed and semi-fixed land. This expansion did also result in shifting sand land expansion.

It is noticeable that increase of semi-fixed sand area is the major achievement of desertification control, and the decreased area of fixed sand is related to the continued reclamation of fixed sand land and grassland degradation. Desertification control is still a great challenge to the efforts of environment improvement and local economic development.

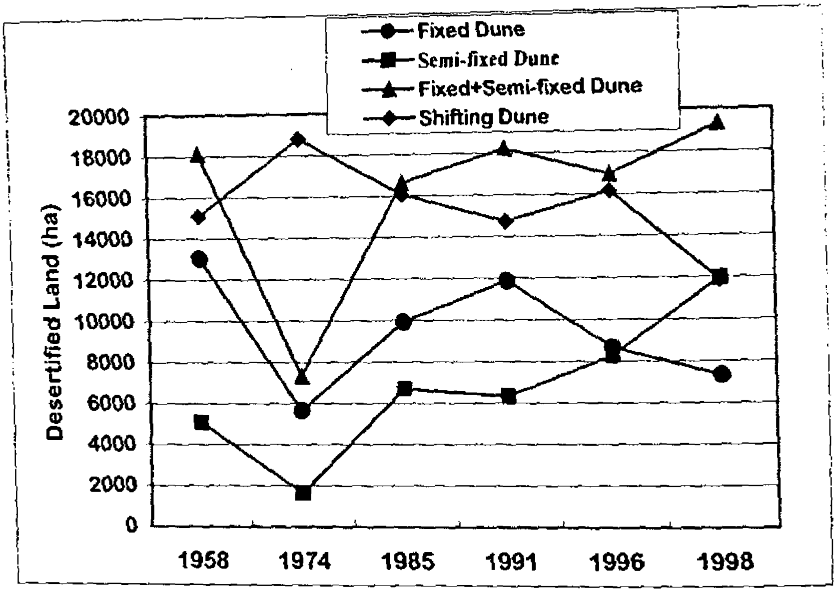

Figure 3. Changes of desertified land in Horqin Sandy Land (Chang Xueli, 2001)

Reduction of Water Availability

Horqin Sandy Land was relatively rich in water resources. Over utilization, however has greatly reduced the water availability and imposed a severe impacts on environment too.

Before the middle of 1980s, the averaged underground water table here was 2-5m, but since then, the underground water table consistently decreased to seven meter in 1999 and down to eight meter in 2001. Increase in the depth of underground water table is related to precipitation (Zhao Halin, 1999); however, the growing demand on water for irrigation played an important role, too.

Lowering of underground water table was also demonstrated with the decrease and eventual drying up of the West Lake, which was one of largest water bodies in Horqin Sandy Land. The West Lake had an averaged reserve of 50million m^3 in the past. But since 1995, the water level consistently reduced and at last dried up on May 17, 2001, while the irrigated cropland increased around it.

Measurement showed that from 1995 to 2001, the water table of the West Lake decreased by more than two meters. The decrease was mainly attributed to the growing consumption of water for irrigation. From Figure 4, it is clear that the water table of West Lake had been decreased far before the drought in years of 2000 and 2001.

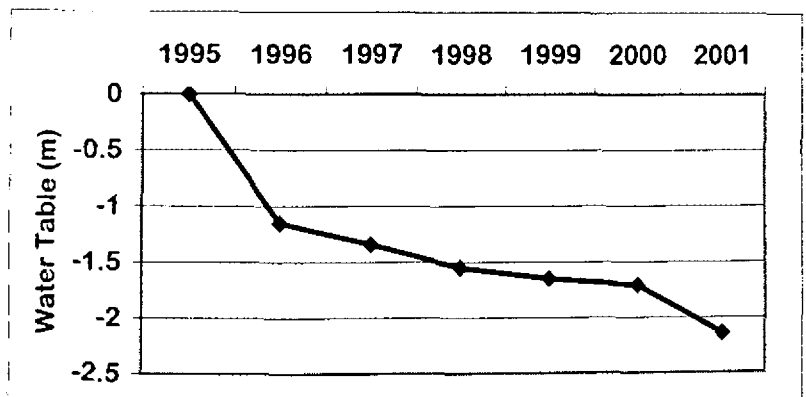

Figure 4. Change of the West Lake water table in Naiman, Inner-Mongolia

In addition to the drying up of the West Lake, reduction of water availability was also presented in the reduction of runoff of the river systems in Horqin Sandy Land. The Xiliao River and its major tributary Xinkai River was the largest river system in this region and played a vital role in the environment and economic development. However, in the past 50 year, over exploitation of water resources has put a great stress on the runoff change of the river.

Measurements at the three sites, Sanhetang on the Xinkai River, Daxinye on the upstream and Tongliao on the middle stream of the Xiliao River showed that the annual runoffs of Xinkai River and Xiliao River were reduced in the past 50 years. The maximum annual runoff of Xinkai River was 0.16 billion m^3 at Sanhetang in 1967, and Xiliao River 0.62 billion m^3 at Daxingye and 3.38 billion m^3 at Tongliao in 1959. These figures were reduced to zero in 1999. Drying-up of rivers due to over exploitation is getting common in northwest, north and northeast part of China. It causes great concerns of the economic development, environment and even the survivals of lives, people and animals in the future.

From the above, it is obvious that the reduction of water reserve in Horqin Sandy Land is closely related to water use because it was already reduced before the drought of 2000 to 2001.

The above analysis showed that in a sense, successes had been made in desertification control in Horqin Sandy Land, but the mismanagement of land resources, has led to the decrease of underground water, rivers' drying up and water body shrinkage. This kind of trend will definitely compromise the basis of environment conservation and at last would be turned into a threat to the life and economic development in this area, if measures conducive to halting this trend are not adopted, immediately and properly.

Conclusions

From the above analyses, the following can be tentatively concluded. The simultaneous occurrence of none-rainy and windy season, and vegetation wilting in the winter and spring was the major natural factors leading to the increasing fragility of ecosystems. Mismanagement of cropland, characterized with the improper selection of land for cropping and rapid expansion of irrigated land, over consumption of underground water and improper timing of tillage wêre major human causes of land degradation. Expansion of irrigated cropland greatly increased the need of water and unleveled land wasted a great amount of limited water at the same time. In this region, the averaged amount of water for irrigating one Chinese mu cropland is around 50t, however, this figure could be increased to 70-80t per mu and even to the maximum of 100t corresponding to the degree of slope or slope patches existed in the cropland and the severity of drought. Leveling the cropland could save about one third of water for irrigation. A no-tillage approach could greatly reduce the loss of soil organic matter. The no-tillage soil had an organic matter content of 108.0kg/mu, while the soil organic matter contents were 99.0kg/mu and 62.0kg/mu in the irrigated land and rainfed cropland, respectively.

The buried depth of underground water was increased from 5.42m in 1979 to 7.42m in 2000 and nearly eight meter in 2001. Together with disappearance of West Lake in 2001, and drying up of

Xiaoqinghe in 1994, and Jiaolai River and Xiliao River in 1999, reduction of water resource availability became a great challenge or even a threat to the local and regional ecosystems and land degradation reversion.

In the past 50 years, progresses have been made in desertification control in Horqin Sandy Land when desertification control was assessed principally in term of vegetation recovery. From 1958 to 1998, the shifting sand was reduced from 15091.3ha to 11866.9ha while the semi-fixed sand area was increased from 5082.6ha to 11972ha. It is noticeable, however, that the fixed sand was reduced from 13035.6ha in 1958 to 7321ha in 1998. With the increase of population and pursuing for increasing income, it is difficult to reduce the impacts of human activity on the land resources, and desertification control is still a great challenge to the environment protection and economic development in Horqin Sandy Land.

Other than development of water-saving technique of irrigation, proper selection of land for cropping, leveling off the land, no-tillage or tillage in the spring immediately before seeding were helpful to avoiding land degradation and reduction of water consumption.

Acknowledgements

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Evaluation of Management for Combating Desertification in Horqin Sandy Land

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Introduction

Land degradation is an increasing environmental problem worldwide. In Jirem prefecture, eastern Inner Mongolia, the area of desertified land has increased from 20% in the 1950s to 54% in the 1970s (Zhu et al., 1988). This area is in a semiarid zone where moisture and vegetation conditions are much better than that in arid zones. The main cause of land degradation appears to be human activities such as overgrazing and overcultivation. Once excessive human pressure is removed, desertification-prone land can be rehabilitated.

Many measures to control desertification were developed in China. But little is known that vegetation and soil productivity can be controlled or recovered by those measures or not. So, we studied vegetation and soil property changes by adapting such measures as controlling of grazing intensity, burying straw or stem, planting shrubs, afforestation, and fertilization, etc. to evaluate the effectiveness of such measures.

This study conducted as cooperative research project between National Institute of Agro-Environmental Sciences, Japan and Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Science.

Evaluation of desertification in Horqin sandy land

Horqin sandy land, located in Jirem prefecture, eastern Inner Mongolia, is sandy plain of Xiliao river basin. Naiman county-the study area- is in the southern part of Horqin sandy land and it is under semi-arid weather condition. Mean annual temperature is about 6.5°C. Mean annual precipitation is about 370 mm, 70% of which is concentrated in summer. Recently, an increase in human activity has caused fixed sand dune remobilisation especially in dry and windy season - winter to spring.

We classified the desertification types into main five types with topography, vegetation and soil type (please see Figure 2). The desertified area expanded to the front of Da Hinngan Lin mountain area from type 3 to type 5. The appearance rate of *Agriophyllum* *squarrosuma* or *Artemisia halodendro* and thickness, particle distribution or organic carbon content of surface horizon is effective index of grassland degradation. Main present issues around this area are how to maintain the degraded grassland or fixed dune against the degradation and how to recover this active sand dune to the fixed sand dune.

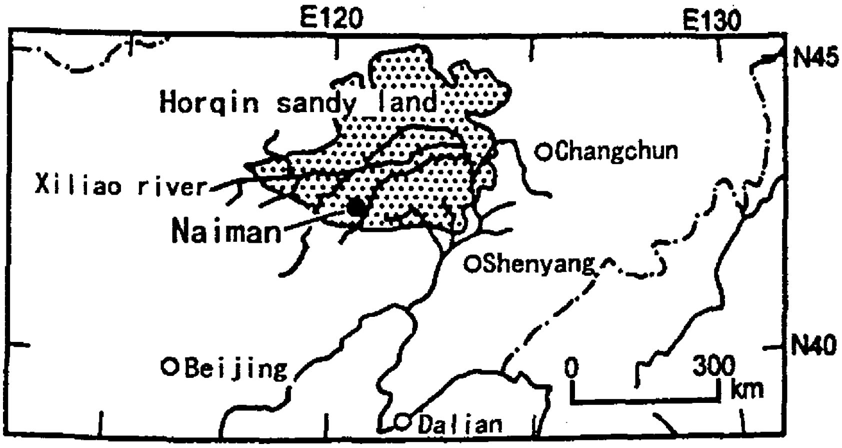

Figure 1. Study area in China

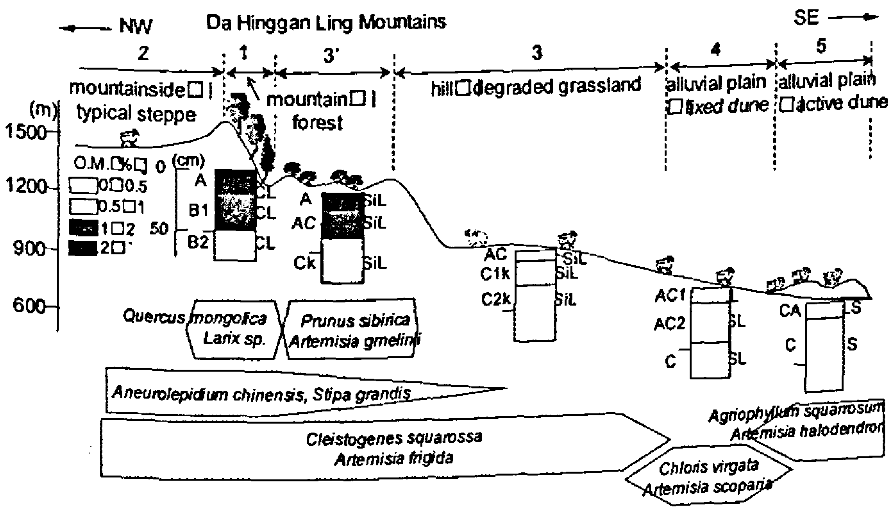

Figure 2. Classification of desertification types in Horqin sandy land

Control of Grazing Intensity

A grazing experiment was conducted on low-relief dunes to clarify the vegetation degradation caused by sheep grazing in Naiman county (Ohkuro, 1998). Four plots with different grazing intensities (6, 4, 2, and 0 sheep/ha) were fenced with barbed wire on a homogeneous grazing pasture and changes in vegetation, soil, and topography were monitored for four years. In the grazing experiment, biomass production changes closely related to livestock production were measured by movable cage method.

Although biomass production decreased with an increased grazing intensity, drastic changes did not occur, even in heavily grazing plots (6 sheep/ha). However, the proportion of species with less palatability and lower nutrient content, such as *Aristida adscensionis* and *Artemisia scoparia*, increased, which indicates that the forage quality deteriorated with the increase in grazing intensity (Figure 3). Such changes occurred drastically in the course of the experimental period. Moreover, the sheep weight in 6 sheep/ha plot decreased by 10% beginning with the third year of the experiment (Figure 4). These results suggest that a qualitative change in biomass production would greatly influence the sheep's consumption and productivity.

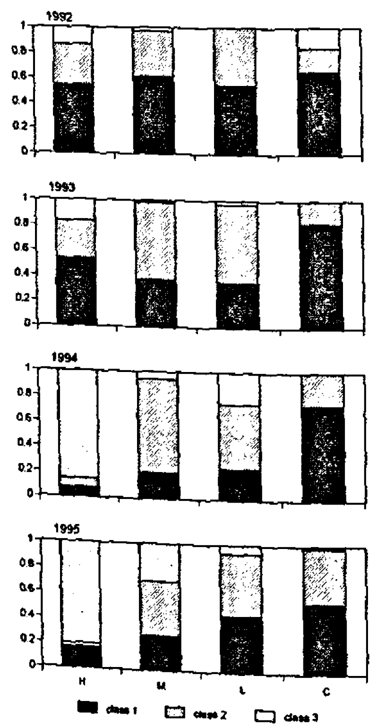

Figure 3. Composition change of vegetation in grazing experimental field

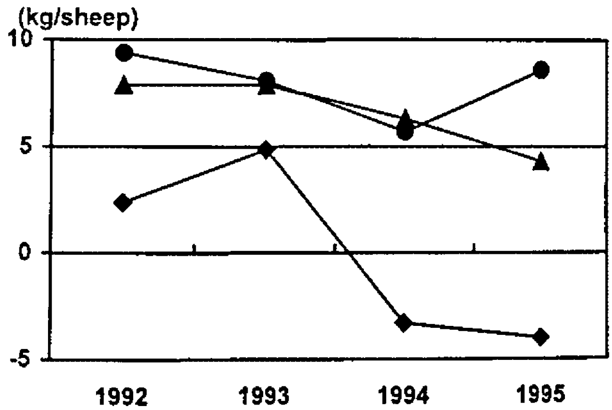

Figure 4. Changes in the gain of sheep weight.
□: 6 sheep/ha, ▲: 4 sheep/ha, ●: 2 sheep/ha.

The grazing intensity also affects the soil properties. The soil hardness increased with compaction by sheep feet and total carbon content decreased with soil erosion in heavy grazing intensity plot, because vegetation cover decreased and the proportion of annual species increased in heavy grazing intensity. This result shows that over grazing directly affects the vegetation cover and changes soil property to decrease the soil productivity.

Vegetation Recovery with Grazing Control

The vegetation cover and composition of plant species were determined year by year after the grazing experiment (Ohkuro et al., in press). It takes four years to recover the vegetation cover at heavy grazing intensity plot (6 sheep/ha) with omitting grazing (Fig. 5). A number and composition of plant species, however, did not recover until four years at heavy and medium grazing intensity plot (6 and 4 sheep/ha). Therefore, we concluded that the appropriate grazing intensity of this area is 2 to 3 sheep/ha to maintain not only the grass biomass and the favorable composition of grass species but also maintain the soil productivity.

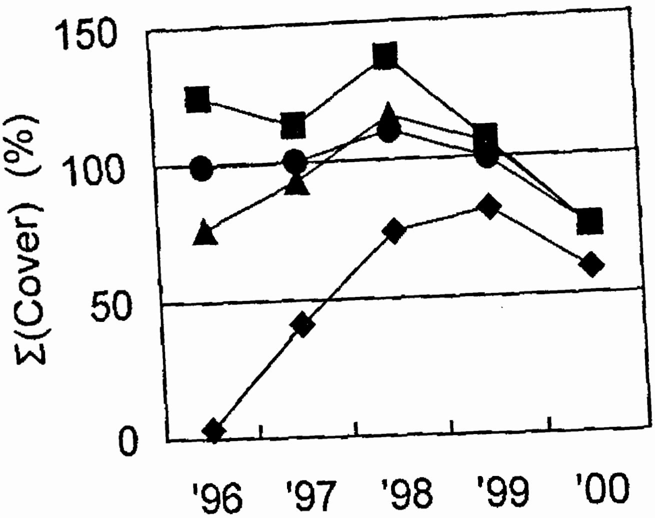

Figure 5. Changes of vegetation cover after the grazing experiment
□: 6 sheep/ha, ▲: 4 sheep/ha, ●: 2 sheep/ha., ■: 0 sheep/ha

Improvement of Grassland Vegetation with Fertilization and Irrigation

Fertilization and irrigation experiments were conducted at a grazing pasture in Naiman, to evaluate the effect of the measures for grassland improvement (Ohkuro et al., 1998). The results of fertilization experiment were as follows; Fertilization had no effect on species composition. However, aboveground dry weight increased significantly with increasing amounts of nitrogen and phosphorus. Especially, the effects of nitrogen on the growth of annuals of *Gramineae* and *Chenopodiaceae* were significant.

Irrigation had little effect on the growth. It might be caused by inappropriate irrigation timing, and rapid penetration of irrigated water because of sandy soil with low water holding capacity.

Fixing Moving Sand Dune

We fenced a shifting sand dune and constructed several plots with different sand fixation measures such as burying corn stems in lines, burying wheat stems with a checkered pattern, or planting seedlings of sand fixing shrub, *Artemisia halodendron*, etc. After the construction, we situated permanent quadrats and have been monitoring changes in vegetation and soil properties since 1996 (Ohkuro et al., in press). We also measured topography using a light wave range finder (Shirato et al., in press).

While a peak of a neighboring sand dune without measures moved more than thirty meters in three years, experimental dune was almost fixed (please see Figure 6). It is obvious that those measures are quite effective in sand fixation.

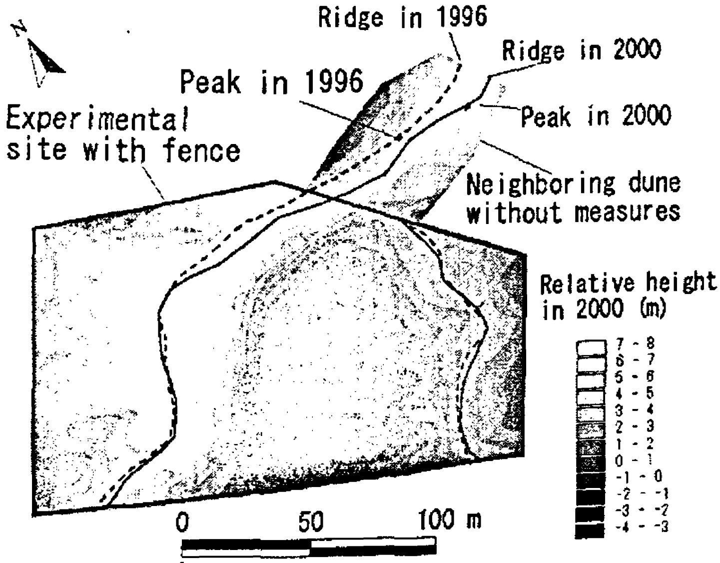

Figure 6. Topography change of experimental site

Vegetation recovered quickly on the plots with dead plant materials such as corn stems and wheat stems (please see Figure 7). Especially on the plot with straw board, perennial grass was also observed. Vegetation cover on the plot of corn stems, however, decreased in the third and fourth year, because corn material was gradually blown away or buried. On the other hand, on the plot with planting *A. halodendron*, few invading plants was observed, although *A. halodendron* itself grew very well, which might be caused by soil moisture or nutrient competition.

Those results of the survey suggested that the process of vegetation restoration differed between physical and biological measures. The application of biological measures such as planting shrub, could promote to cover land surface quickly, in other words, contribute to the recovery of biomass production. On the other hand, physical measures such as straw checkerboard and stem belt, can lead invasion of various species, or, contribute to recovery of species-rich community.

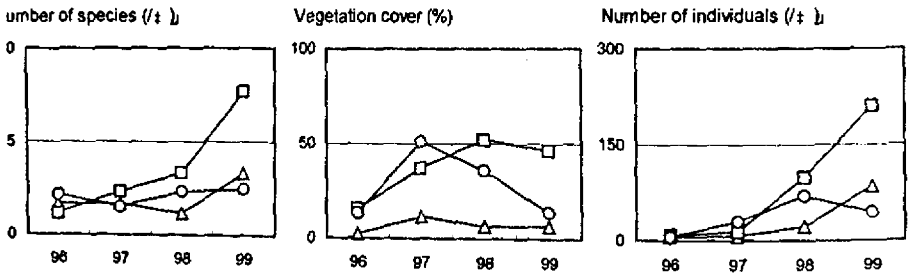

Figure 7. Vegetation change at three plots of different sand fixation measures from 1996 to 1999
□: plot of straw checkerboard, □: plot of planting *A. halodendron*, ○: plot of corn stems

The amount of fine particles and organic carbon content of surface soil increased in some plots in three years (please see Figure 8). The amount of available nitrogen and phosphorous increased also. It is considered that some of these treatments are quite effective so that soil properties changes in short term. However, it is difficult to evaluate the effectiveness of each treatment because the position of every treatment is not distributed equally, though the position of treatment in sand dune affects the results. For example, soil properties were different between windward slope and leeward slope in same treatment. The effect of position has to be evaluated to estimate the effectiveness of each treatment.

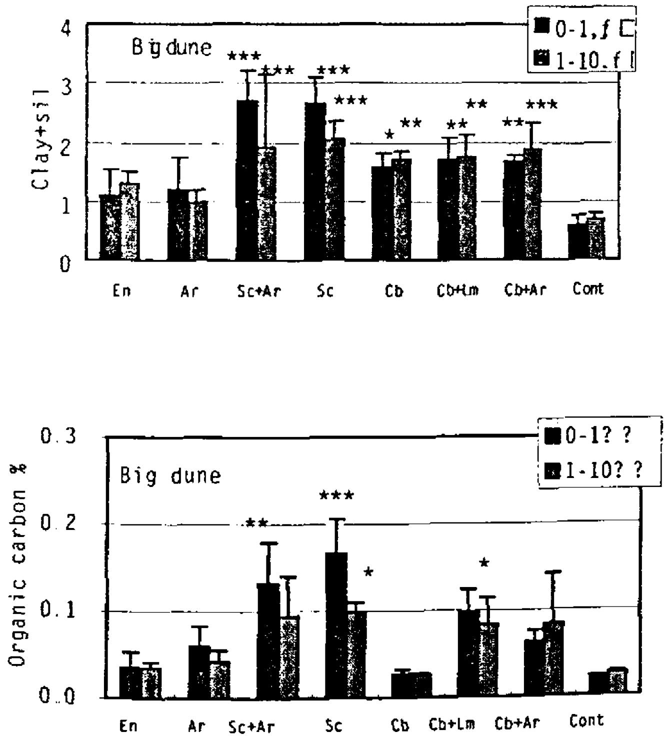

Figure 8. Effects of sand dune fixing measures on soil properties. En: Enclose only, Ar: Planting A. halodendron, Sc: Straw checkerboard, Cb: Corn stem belt, Lm: planting legume, Cont: Control

*, ** and *** indicate difference with control of same depth was significant at the 0.05, 0.01 and 0.001 probability level, respectively.

Afforestation

We measured soil property in poplar planting field for fixing sand dune after 3, 9, and 20 years and sand dune near the forest. The poplar forests are several hundred meters square and the soil samples were taken from center position of the forest with each soil horizons (Shirato et al., in press).

Organic carbon content and the amount of fine particles such as clay and silt of surface horizon increased with the year after plantation of poplar (please see Figure 9). It is considered that poplar forest effectively prevented the loss of fine particles by wind erosion, caught fine particles transported by wind, and accumulated organic matter. Soil properties such as available nitrogen, available phosphorous and CEC (Cation Exchange Capacity) of surface horizon also increased with the year after plantation and caused increase of soil productivity. This effect appeared clearly in 20 years plantation, but it did not in 3 and 9 years, so the time more than 10 years seems to be needed to appear the effect of afforestation on soil property. However, we considered that it takes 20 years to recover the soil productivity in afforested filed, comparing soil properties with grassland or upland field which was uncovered with sand. Then, we suggest that it is possible to cut the forest for developing grassland or upland field after 20 years afforestation leaving the edge of the forest for the windbreak.

Conclusions

Many measures to control desertification were developed in China. But little is known that vegetation and soil productivity can be controlled or recovered by those measures or not. So, we studied vegetation and soil property changes by adapting such measures as controlling of grazing intensity, burying straw or stem, planting shrubs, afforestation, and fertilization, etc. to evaluate the effectiveness of such measures. The study area is in the southern part of Horqin sandy land, located in eastern Inner Mongolia.

The plant production decreased and the proportion of species with less palatability and lower nutrient content increased with increasing in grazing intensity. The qualitative change in plant production would greatly influence the sheep's consumption and productivity.

It takes four years to recover the vegetation cover at heavy grazing intensity plot (6 sheep/ha) with omitting grazing. A number and composition of plant species, however, did not recover until four years at heavy and medium grazing intensity plot (6 and 4 sheep/ha).

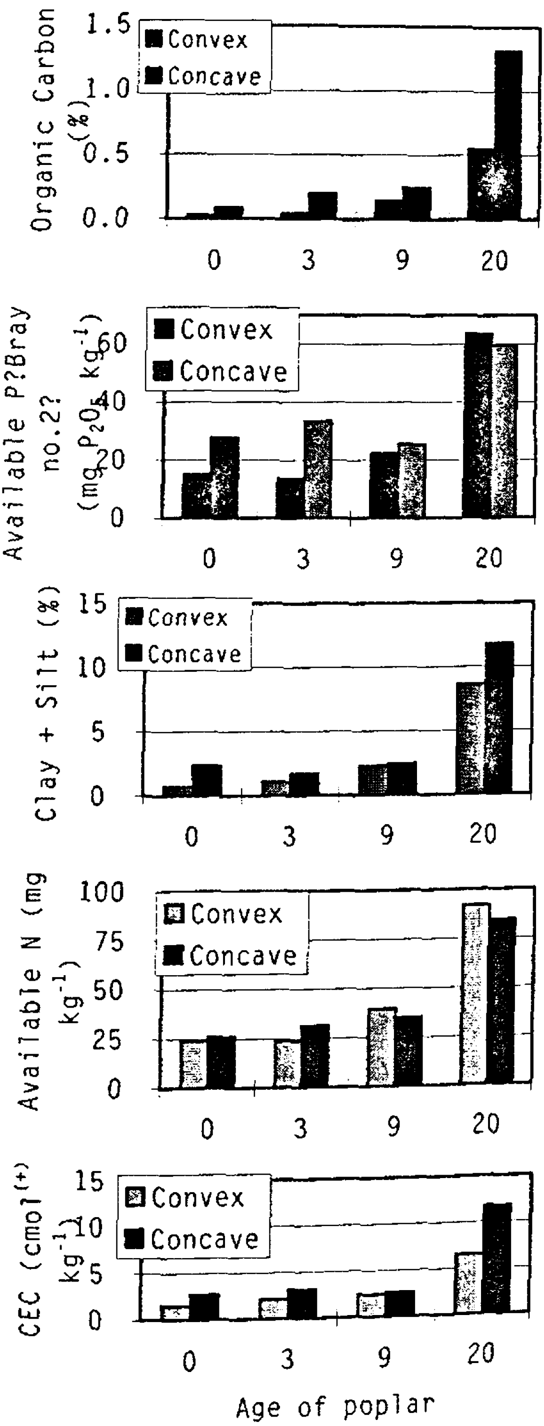

Figure 9. Surface soil property changes with the age of poplar plantation

The supply of nitrogen fertilizer significantly had effect on aboveground dry weight of annual plants. Irrigation had little effect on the growth because of inappropriate irrigation timing and rapid penetration of irrigated water.

The sand dune was almost fixed by enclosing with fence and adapting some measures, whereas neighboring dune without measures moved more than 30 m in 4 years. The application of biological measures such as planting shrub, could promote to cover land surface quickly. On the other hand, physical measures such as straw checkerboard and stem belt, can lead invasion of various plant species, or, contribute to recovery of species-rich community. Surface soil properties such as organic carbon content and the amount of fine particles appreciably increased at some measure's plots in quite short period-3 years.

The amount of organic carbon and fine particles of surface horizon increased with the year after plantation of poplars. It is considered that poplar forest effectively prevented the loss of fine particles by wind erosion and accumulated organic matter with catching fine particles transported by wind.

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Soil Conservation and Land Use Issues in Uzbekistan

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Overview

The total area of the Uzbekistan is 44.5 million hectares. Irrigated lands are of special value in conditions of the arid zone. Although they occupy only 15% of farmlands, they produce over 95% of the gross agricultural output. There are also over 22 million ha of rangelands in Uzbekistan, of which 19.6 million ha, or 88%, are irrigated.

The area of irrigated lands in Uzbekistan is limited by the availability of water in irrigation sources, which have been almost depleted by now. It is understandable that any further growth of the area of irrigated land is only possible through water conservation, improvement of water distribution and resource management techniques, and improvement of the irrigation and drainage conditions of lands. The quality of irrigated lands is characterized by the soil fertility index based on the 100-point scale. The mean assessed soil fertility index for Uzbekistan is 59.

Many years of cotton domination, absence of the required crop rotation and insufficient development of livestock breeding (which caused a deficit of organic fertilizers) necessitated large-scale application of chemical fertilizers and pesticides. All this eventually led to destruction of natural biological processes and degradation of natural regulation mechanisms, and turned soil from a complex ecological system into a media for transporting the applied chemical fertilizers to the root system of plants.

On the basis of analysis of agrochemical and ecological conditions of agricultural and natural soils of Uzbekistan the main problems were identified and possible solutions which could improve situation in a future. These solutions include activities such as introduction of new schemes of crops rotation, application of higher rates of organic fertilizers, cultivation of legumes, and better utilization of water resources. These are part of a development of land resources in both irrigated and rainfed areas in the interests of the country's sustainable development. These activities will prevent or reduce the scale of land degradation and will allow rehabilitate partially degraded lands.

Geographical location and climate

The Republic of Uzbekistan is located in the center of Eurasia, as shown in Figure 1. Almost four of fifth parts of it is territory are situated in Central Asian deserts and semi-deserts which are bordered on the southeast and east with high mountain system.

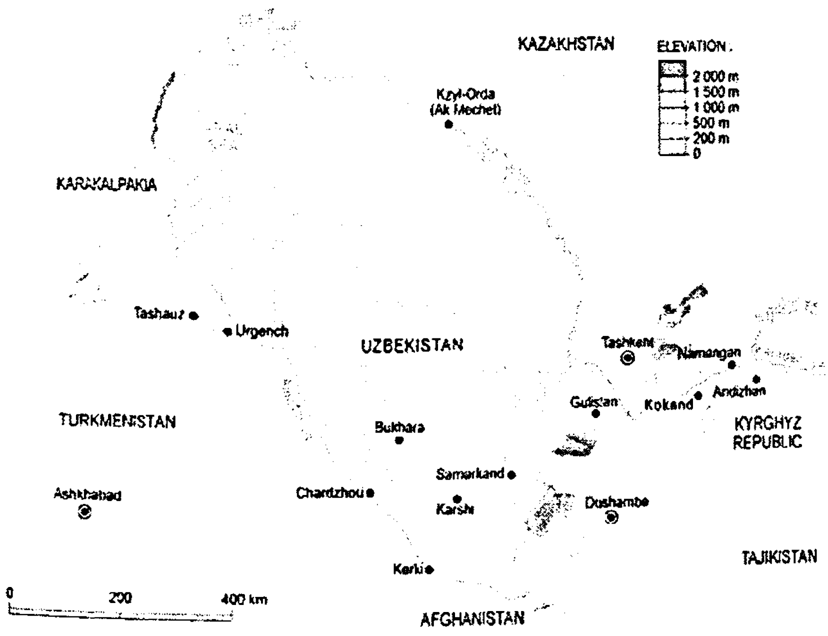

Figure 1. Map of Uzbekistan.

The main climate generation factor on the territory of the Uzbekistan is intensive flux of solar radiation especially in summer months. Coming air masses of middle latitudes in the system of general circulation as well as from the Atlantic region, are actively, and heated over the scorched deserts. Their relative humidity is decreased. The humid air mass from the Indian Ocean cannot overcome mountain range of Himalayas, Hindukush and Pamirs-Alaj. Thus, the conditions for formation of hot and dry summer exist in Central Asia including Uzbekistan.

In winter, cold mass of Arctic air sometimes invades the Central Asian plains. Therefore, the winters here can be quite severe. However, much more often warm air from Persian Gulf and

Arabian Sea penetrates in to Central Asia creating mild winter conditions. Because of the interaction of three factors: intensive solar radiation, atmosphere circulation and mountain relief of Central Asia the climate of greater part of Uzbekistan is subtropical and extra continental, with steady summer weather and unstable winters and large seasonal and daily air temperature amplitudes.

Relief and Geomorphology

According to the structure of its surface territory of Uzbekistan is comprised of two unequal parts. Plains occupy three quarters (78.7%) of its territory, while the rest (21.3%) of it are a mountain and inter –mountain depressions. The country's territory is gradually rising from the West and Northwest towards the East and Southeast. The mountains situated in the East and Southeast are edged with mountain foothills called 'adyrs'. Plains and lowlands have patches of residual plateau dating back to the pre-Quaternary period. They mostly lie in the northern and northwestern parts of Uzbekistan. The plains are a part of the Turanian lowland, which used to be the bottom of a shallow sea in the distant past. As the sea receded towards the West, it left behind loose sedimentary rocks brought by rivers from the mountains. When the sea had dried out, the sand the silt deposits contained clayey rocks. Layers of clay mostly deposited in mountain foothills and river valleys.

Mountains and foothills with a severely broken relief are mostly situated in the East and Southeast of Uzbekistan where they join powerful mountain ranges, also severely broken, in the territory of Kyrgyzstan and Tajikistan. As the mountains become lower towards the West and Northwest, the inter-mountain depressions become wider. They gradually merger with the vast Turanian Lowland, which occupies almost the entire territory between the Syrdarya and Amydarya rivers. This vast territory has very peculiar physical and geographical conditions, and is diverse from the geomorphologic point of view. Within the boundaries of Uzbekistan it is characterized by a variety of areas differing in their genesis and relief.

Soils

Various natural factors have caused the formation of the following types of soils in the territory of Uzbekistan: floodplains-alluvial, meadove-grey, sandy desert, takyr desert, solonchaks, gray-brown desert, irrigated (cultivated) gray, light-gray, common (typical) gray, mountain-brown and alpine meadow.

The dry climate is the cause of weakly manifested soil-forming processes in its territory. Since soil formation is slow, the time factor is of great importance. All soil types are formed and developed over deeply-lying groundwater and belong to automorphous, or self-forming soils whereas in conditions of excessive moisture-in valleys, floodplains and river deltas-develop hydromorphous soils such as meadow-alluvial, meadow-marshy, marshy meadow and others develop. Their formation is associated with the shallow-lying groundwater capable of moistening through capillaries the entire soil layer lying above them. Thus they secure the development specific marsh and meadow vegetation, vertical and horizontal salt migration and such like.

Land Resources

The total area of the Republic of Uzbekistan, as of January 1, is 44.5 million ha. Farmlands occupy 62% of the country's territory. Irrigated lands are of special value in conditions of arid zone. Although they occupy only 15% of farmlands, they produce over 95% of the gross agricultural output. However, the area of irrigated lands in Uzbekistan is limited by availability of water in irrigation sources, which have almost been depleted by now. Therefore, any further growth of the area of irrigated land is only possible through water conservation, improvement of watering techniques and methods, and improvement of the irrigation and drainage conditions of lands. About half (46.8%) of irrigated farmlands are saline, of this mount 25.2% have weak, 15% medium and 6.6% strong salinity.

The quality of irrigated lands is characterized by the soil fertility index (based on the 100-point scale). The average soil fertility index in the Republic of Karakalpakistan is 41, in Syrdarya province 52, in Jizak and Kashkadarya provinces 54, in Bukhara and Navoi provinces 59, in Namangan province 63, in Fergana province 64, in Andijan province 65, in Samarkand and Tashkent provinces 66, in Khorezm and Surkhandarya provinces 68, and the average for Uzbekistan is 59.

Rain-fed (non-irrigated) lands, with a total area of 800.000 ha, are mostly situated in the foothills (at an absolute altitude of 400 up to 1000 m above sea level), where the mean annual precipitation is 300 to 500 mm and more. In conditions of the broken relief of foothills and sloping plains most of the rain-fed lands are represented by soils washed out to a varying extent due to many years of ploughing and water erosion.

There are over 22 million ha of rangelands in Uzbekistan, of which 19.6 million ha, or 88%, are watered. Uzbekistan belongs to the most ancient regions of human use of rangelands in the world. With the total rangeland area of 22 M ha and the present population of more than 25 M humans, Uzbekistan remains highly dependent on livestock production from natural rangelands, though during the past 30 years the significance of farm livestock husbandry and animal feed production on cultivated fields has continuously increased. There are several ways for rangeland utilization such as grazing, fodder preparation for wintertime, firewood collection, etc. Recently, the rangelands of Uzbekistan were converted into croplands mostly for cultivation of cereals. Overgrazing is a main factor of desertification in Uzbekistan. Thinness of vegetation and low productivity of desert phytocenoses cause considerable loss and a very small number of wells in deserts intensify this process sharply. As a result of overgrazing endemic vegetation changes dramatically within a radius of 2-3 km around watering points, and is completely destroyed within half a kilometer. In the areas of overgrazing the number of plant varieties in phytocenoses decreases 2 to 4 times over. Depending on natural conditions, they are divided into desert plains with an area of 18 million ha, hillocky plains with an area of 3.2 million ha, and foothills-mountains with an area of 0.9 million ha.

Options for Sustainable Development in Uzbekistan

Soil Conservation

Logistical, economic and agrotechnical activities of soil conservation. These activities aim to prevent the destruction of the topsoil layer and increase the fertility of eroded lands. They are also part of the farming techniques in crop farming on degraded soils.

Crop Rotation

Crop rotation leads among the recommended activities. On most degraded soils and in the areas of strong and medium winds soil-protecting crop rotations are used, based on the use of crops covering the land surface during the greater part of the vegetation period.

Land Tenure and Grazing Approaches

Of all logistical, economic and agro-technical activities aiming to protect ploughlands against degradation and raise their productivity, grazing regulation and phyto-reclamation are most important ones. Public control over the state of the environment and use of land and water resources is of great importance for agricultural production.

Monitoring and Surveillance

Considering the great importance of land as natural resource, the land surveillance service, along with the land use inspection, have been separated from the ministry of Agriculture and Water resources. On this basis, the State Committee for Land Resources was established and subordinated directly to the Cabinet of Ministers. The same is expected to be done in the field of water resources management. Under the control and guidance of this ministry, it the State Committee has performed total land valuation works all over Uzbekistan. Laboratories and research stations were involved into this survey. On the basis of two year research work, several maps (soil map, soil salinity map, land valuation map, crops distribution map) with a resolution of 1:25,000 were prepared. This survey was also used as the basis for a set of recommendations for better utilization of land and water resources of 20 farms in Jomboy and 16 farms in Taylok districts of Samarkand region. These maps were distributed free of cost.

It is planned to repeat these surveys once every 5-10 years. These are planned in a manner to extend the investigation to rain-fed areas and to prepare similar maps. These maps will be distributed to farmers for better management of rain-fed area.

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9

A Method to Separate Anthropogenic Effect Out of the Desertification Process

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Introduction

Quantitative assessment of anthropogenic effects on eco-economic systems is an area under active research in the world today and many scholars have undertaken significant work on its various aspects (Anderies, 2000; Jager et al., 2000; Bossel, 2000). Desertification is a global issue to be considered in the context of eco-economic problems and the quantitative research of the contribution of anthropogenic factor to the desertification process has always been a central problem in the study of desertification causes (Wu, 1991; Zhu, 1989). The quantitative analysis of the anthropogenic effect on the desertification processes will no doubt contribute to a better understanding of the mechanism of desertification and to settle the dispute as to which one, anthropogenic factors or natural factors, is the main cause responsible for desertification (Dregne, 1986; Sabadell et al., 1982).

At present, two major methods are used to make quantitative study of anthropogenic effect on the desertification processes. The first method is the use of simulation experiments to study the relationship between wind erosion rates and wind erosion factors in the wind tunnel (Dong et al., 1987; Liu et al., 1992; Dong et al., 1995). The purpose of this experiment is to demonstrate the influences of anthropogenic factors such as soil tillage (land reclamation), fuelwood collection, grazing and animal trampling on soil wind erosion, etc. Experiments in this respect have proved that under similar natural conditions soil erosion rates may be increased from less than 10% to more than 100 times due to irrational human economic activities. Hence, these activities are the main anthropogenic factors responsible for the exacerbation of land desertification in grassland regions.

However, there are still some difficult problems in the wind tunnel simulation experiments of desertification factors. First, in the wind erosion experiment in the wind tunnel we cannot simulate several factors simultaneously. Existing experimental results only represent the relation of the marginal changes between single factors and wind erosion rates on condition that other factors are held constant. Second, there is no theoretical model to support the separating and overlapping influences of various factors on soil wind erosion.

Therefore, it is generally difficult to weigh the contribution of anthropogenic effect.

The second method is to analyze the historic records and the desertification reversing degree after long-term grazing exclusion in the typical regions. From the above analysis it can be concluded that present-day desertification resulted from irrational human economic activities, i.e. man is the main cause of desertification (Zhu et al., 1989; Wang, 1983; Chen, 1986). However, such analysis is qualitative rather than quantitative. This paper intends to establish a mathematical model to measure the anthropogenic effect on the desertification processes on the basis of geomorphological evolution.

Dynamic Mechanism of Desertification Process

Geodynamic theory indicates that geomorphological evolution is controlled by two processes, i.e. internal forces and external forces (Scheidegger, 1979). Generally speaking, internal forces lift the ground surface of the denuded area, while external forces abrade the ground surface and thus reduce the height of the ground surface. In such a case, the action of internal forces are considered to be primary, i.e. in the geomorphological evolution process the landforms are not only subject to the effect of internal force but also subject to the effect of external forces such as wind, running water and glaciers etc. The complex and diversified surface features are the manifestations of the action of internal and external forces at the present day (Scheidegger, 1985). If the internal forces are relatively stable, the external forces will be the main erosion force, in such a case, the landform system can be approximately viewed as a closed system (Ai, 1987).

In fact, the geomorphological evolution process in an eroded area is also the soil erosion process. In order to distinguish the difference between internal and external forces, the running water-dominated erosion is called water and soil losses, while the wind-dominated erosion under loose sandy surface condition is referred to as desert or desertification process. In the history of mankind people have been reclaiming land, grazing and engaging in various production and management activities for their existence. This has no doubt affected the desertification processes. Accordingly, considered from the dynamic mechanism of desertification process, three processes, namely internal forces process, external forces process and anthropogenic effect process, are co-existent and can be expressed by the following formula:

$$Y(t)=\begin{bmatrix} E_n(t) \\ E_x(t) \\ H_m(t) \end{bmatrix}$$

In the Formula, $Y(t)$ represent desertification processes; $E_n(t)$ represent internal forces processes; $E_x(t)$ represent external forces processes; and $H_m(t)$ represent anthropogenic effects processes. Various surface features left by different phrases of desertification processes are the combined results of above-mentioned three processes.

Unlike external forces, anthropogenic effects do not directly join in the desertification processes, it can only change local surface features and vegetation cover through human production activities and land management methods, thus indirectly accelerating or delaying the desertification processes. Anthropogenic effects $H_m(t)$, may be positive or negative with respect to desertification. If human production and management methods are improper, such as overcultivation and overgrazing, the desertification process will be inevitably exacerbated. In such a case, the effect of human activities on desertification is positive. On the contrary, if human activities halt desertification and soil erosion, desertification tends to reverse. In such a case, the effect of human activities on desertification is negative. The purpose of desertification control is to make the result of $H_m(t)$ negative using various measures and thus delaying wind erosion processes. Measures to combat desertification generally include both biological and engineering measures, which are complementary each other (Zhu et al, 1998). However, all these measures, whether they are biological or engineering, can only change the external force processes of desertification rather than its internal force processes.

Mathematical Model for Quantitative Analysis of Anthropogenic Effect on Desertification Processes

Generally, we are unable to define a concrete function form of internal force effects but we can make a preliminary judgement. First, they are a function of time and space f(x,y,t). Second, the geomorphological processes of internal forces are relatively independent in time and space (Hirano, 1968). Hence, we can separate variables in the function, namely

$$f(x,y,t) = \phi(x,y)T(t) \qquad (1)$$

According to Davis's theory of geomorphic cyclical development, the effect of internal forces on landform evolution is only manifested in the initially rapid uplift of flat surfaces. Afterwards, the landform goes through the adolescent, mature and old stages, all of which can be regarded as further reworks of external forces to the landform. This process can be described by the mathematical relation:

$$\lim_{\Delta t \to 0} \int_0^{\Delta t} T(t)dt = 1 \qquad (2)$$

Davis's geomorphic development theory is in fact a landform evolution theory of a closed system, clearly this is its limitation.

Strictly speaking, a landform system is an open system dealing with three basic processes namely internal force processes, external force processes and anthropogenic effect processes. For the internal forces, it may be strong at one time and weak at another time. There are also strong or weak differences in its spatial distribution. Therefore, viewed from geologic history, T(t) has the following form:

$$T(t) = \begin{cases} f(t) \neq 0 & as \quad T_{2k-1} \leq t \leq T_{2k} \\ 0 & as \quad T_{2k} \leq t \leq T_{2k+1} \end{cases}$$

In the meantime it should satisfy:

$$\sum_{k=1}^{\infty} \int_{t_{2k-1}}^{t_{2k}} f(t)dt = 1 \tag{3}$$

In the relatively stable period of internal force (i.e. $T(t)\approx 0$), the desertification mainly results from external force processes and anthropogenic effect process. Viewed from the angle of input and output, desertification is a process during which part of input elements turned into output elements under the condition of a certain anthropogenic effect. Let Y denote output element, M denote the intensity of anthropogenic effect, and $x_1, \ldots, x_n$ denote different inputs of natural elements respectively, we obtain the following mathematical equation of desertification process:

$$Y = Mf(x_1, \Lambda, x_n) \tag{4}$$

Where $M, x_1, \ldots, x_n$ are the function of the time t.

Among various factors affecting the desertification, external force factors such as the precipitation and its intensity, and the wind velocity etc. can be obtained from observation data, but the effect of human activities on desertification is very difficult to be described by observation data. For quantitative analysis of the effects of human activities on the output element Y we need to analyses the Equation (4). By differentiating both sides of the Equation (4) we obtain:

$$\frac{dY}{dt} = \frac{dM}{dt} f(x_1, \Lambda, x_n) + \sum_{i=1}^{n} \frac{\partial Y}{\partial x_i} \cdot \frac{dx_i}{dt} \tag{5}$$

Dividing both sides of the Equation (5) by Y, and we write

$$\alpha_i = \frac{\partial Y}{\partial x_i} \cdot \frac{x_i}{Y} \tag{6}$$

Then

$$\frac{dY}{Ydt} = \frac{dM}{Mdt} + \sum_{i=1}^{n} \frac{\alpha_i dx_i}{x_i dt} \tag{7}$$

This is the increasing rate equation of output element of the desertification process. Its left side is the change rate of output element of the desertification process and the first term at the right side of the equation is the change rate of input natural elements.

Because the original data such as Y, M, x_1, ..., x_n are discrete data, in the actual application, if the time interval Δt is small, we can use the difference equation to approximately represent the differential equation (7), namely

$$\frac{\Delta Y}{Y\Delta t} = \frac{\Delta M}{M\Delta t} + \sum_{i=1}^{n} \alpha_i \frac{\Delta x_i}{x_i \Delta t} \tag{8}$$

If Δt in various terms of above equation represents the same time interval, we may write:

$$\frac{\Delta Y}{Y} = \frac{\Delta M}{M} + \sum_{i=1}^{n} \alpha_i \frac{\Delta x_i}{x_i} \tag{9}$$

Equation (9) is the mathematical model we use to measure the degree of anthropogenic effect. It means that the increase in output element of desertification results from the increase in input element and the eco-environmental destruction by anthropogenic effect (here both the "increase" and "destruction" are negative.). Because the values of input natural elements are obtained from the analysis of historic data, once the parameter α_i are figured out by appropriate methods, the change rate of anthropogenic effect $\Delta M/M$ can be worked out as the remainder. The contribution of anthropogenic effect to the output element of the desertification can be calculated by the following equation:

$$K_1 = \left|\frac{\Delta M/M}{\Delta Y/Y}\right| \times 100\% = \left|1 - \frac{Y \cdot \sum_{i=1}^{n} \alpha_i \frac{\Delta x_i}{x_i}}{\Delta Y}\right| \times 100\% \qquad (10)$$

The contribution of input natural element to the output elements of the desertification is

$$K_2 = 100 - K_1 \qquad (11)$$

Calculation Methods of Precipitation and Wind Velocity Resiliences

Research shows that from a macroscopical viewpoint the main natural factors affecting desertification in the sand-covered areas are wind velocity and precipitation (Mainguet, 1991; Zhu, 1989). And the relationship between precipitation and desertification can be embodied by the influences of soil moisture content and wind erosion rate. It can be seem from the equation (10) that the calculation of wind velocity resilience α1 and soil moisture resilience α2 is the key to the estimation of anthropogenic effect on the desertification processes.

The implications of wind velocity resilience α1 and soil moisture resilience α2 to desertification are the sensibilities of desertification to wind velocity changes and soil moisture change, i.e., how much changes in desertification will take place as the wind velocity and soil moisture change. We hope to find out the quantitative relation between them, or their functional relation through simulation experiments in wind tunnel. Let field wind velocity $V=x_1$, soil moisture $W=x_2$, the relation between wind velocity v and sand transport rate q in wind tunnel is used to approximately represent the relation between wind velocity V and desertification Y in the field; and the relation between soil moisture content w and wind velocity v in wind tunnel is used to approximately represent the relation between precipitation P and desertification Y in the field.

R.A. Bagnold (1941) suggested the relation between wind velocity and potential sand movement q-v^3 and thereby established the functional relation between wind damage and sand damage. Wu Zheng (1987) and He Daliang (1993) undertook a series of observations and experiments on the relation between wind velocity and sand transport rate and obtained a result similar to Bagnold's observations. Our wind tunnel experiments on the relation between wind velocity and sand transport rate also confirmed this result, as shown in Table 1.

Table 1. Relation between sand transport rate and wind velocity

v (m/s)	8.3	9.5	10.5	11.5	13.2	13.7	15.8	17.7
q (kg/m.hr)	1.17	1.455	1.77	2.32	3.05	3.9	5.52	8.75

Note: Sand sample used in the experiment is air-dried sand with a mean grain size of 0.1mm.

From the simulation data in Table 1 we obtain:

$$q = 0.334 + 0.0015v^3 \qquad (12)$$

correlation coefficient: $r^2 = 0.9845$

Sand transport rate is a function of the cube of the wind velocity. From this we assumed that a similar functional relation between desertification and wind velocity is present.

$$Y = 0.334 + 0.0015V^3$$

It can be further expressed as:

$$Y = a + bV^3 \qquad (13)$$

Where a and b are constant.

Soil moisture content is one of the main factors affecting the behavior of particle movement. He Daling and Shen Jianyou (1988), Liu Yuzhang and Dong Guangrong et al. (1992) conducted the wind tunnel simulation experiments on the relation between soil moisture content and wind velocity and concluded that soil moisture content is an important factor halting wind erosion, and wind erosion modulus is inversely proportional to soil moisture content.

The author in cooperation with others (Chen et al., 1996) conducted the wind tunnel experiments and established the relation between soil moisture content w and wind erosion rate E_r, as shown in Table 2.

Table 2. Parameters of the formula concerning wind erosion rate and soil moisture content

Wind velocity (m/s)	$E_r = ce^{(dw)}$ c	d	r^2	Significant level of F-test
15	7302.72	-0.7932	0.99	0.001
20	8538.44	-0.6590	0.98	0.001
25	10921.73	-0.5836	0.98	0.001

Source: From *Journal of Arid Environment*, 1996, 34: 400.

From the relation between soil moisture content w and wind erosion rate E_r shown in Table 2, we can approximately infer the relation between desertification degree Y and soil moisture content W as:

$$Y = ce^{dW} \tag{14}$$

Where c and d are constant.

Desertification is related to soil moisture content in surface layer and soil moisture content is highly variable due to the influence of evaporation. Thus far we still have no serial data to make quantitative analysis. In order to get related data we assumed that there is a linear relation between soil moisture content and precipitation, namely $W=kP$, where k is a constant determined by soil property and evaporation, and P is precipitation. Then we get

$$Y = ce^{dkP} \tag{15}$$

Where c, d and k are constant. Substituting equation (13) and (15) in equation (6) we have:

Wind velocity resilience: $\alpha_1 = \frac{\partial Y}{\partial V} \cdot \frac{V}{Y} = 3bV^3 / (a + bV^3)$ (16)

Precipitation resilience: $\alpha_2 = \frac{\partial Y}{\partial P} \cdot \frac{kP}{Y} = kP$ (17)

The wind velocity resilience α_1 is a function of the cube of the wind velocity, while the precipitation resilience α_2 is a function of the precipitation. It should be pointed out that the resilience coefficient is nondimensional, it requires selecting proper unit to express the numerical relation between V and P. If the resilience coefficient is a whole number, the precipitation unit used in the calculation of precipitation resilience α_2 is dm rather than mm.

Analysis of Examples

Ejin Horo Banner, located at northeastern margin of the Mu Us Desert between 108°58′–101°25′ E and 38°56′–39°49′ N, stretches 61 km from east to west and covers an area of 5900.96 km^2. It is one of the most seriously desertified regions of China. Recent desertification in the region began 300 years ago when the Government of Qing Dynasty launched large-scale land reclamation action. Especially in the last 10 years of Qing Dynasty an immigration plan was implemented and a great number of farmers moved from the hinterland to the Ejin Horo Banner. They cut down trees in an uncontrolled manner, destroyed grasslands and reclaimed land, thus resulting in rapid spread of desertified land. During the reign of the Guomintang the undue reclamation was still continuing. By the year 1949 the cultivated land in the area reached 82,143 hm^2. Hence, the former pastureland was no longer able to raise large herds of livestock.

At the beginning of the founding of the New China, the government implemented the policy "prohibiting land reclamation and protecting grassland" and "taking grazing as the main economic activity to promoting the development of agriculture". This greatly halted the land desertification in the region. However, the causes responsible for land desertification are multiple and multilevel due to complex socioeconomic and political backgrounds. With rapid increase in population and grain demand, a wrong policy "putting grain in the top priority position in the agricultural production" was carried out from the mid-1950s to the early 1970s. This led to three large-scale land reclamation movements in the Ejin Horo Banner thereby resulting in the rapid spread of desertification. Other social and economic factors responsible for land desertification include land management rights and livestock ownership issues. Under the condition of public ownership herdsmen and farmers lacked production enthusiasm, were not aware of the importance of resource and environmental protection and managers adopted incorrect strategies, and thus overgrazed, overused the grassland resource, and conducted extensive cultivation with low output. Owing to lower productivity levels and poverty, herdsmen and farmers were forced to excessively cut trees for fuelwood and dig medical plants as an income source. This also accelerated the development of land desertification.

According to the comparison of 1957-1977 aerial photographs made by the Comprehensive Investigation Team of the Loss Plateau, Chinese Academy of Sciences (1991), in the 20 years from 1957 to 1977 desertified land increased from 4716 km^2 to 5684 km^2 in the Ejin Horo Banner region. From 1980s onwards land desertification in the region was effectively controlled and showed a reversing tendency. A ccording to the mapping and measurement of 1986 TM satellite photographs, the area of desertification in the region decreased by 308.6 km^2 compared to that of 1977, on an average 30.7 km^2 were decreased each year.

To determine the contribution of anthropogenic effect to the land desertification process several counties where desertification has a reversing tendency were selected in the present study.

Table 3. Changes in desertification area, wind velocity and precipitation in the Ejin Horo Banner during the study period

Study period	Desertification area (km^2)	Wind velocity (m/s)	Precipitation (dm)
1977	5684.01	8.32	3.424
1986	5375.41	7.49	3.714
Change rate (%)	-5.43	-9.98	8.47

Note: Wind velocity showed in the table are the weighted mean values of >5 m/s threshold wind velocity for sand movement.

Calculation of wind velocity resilience coefficient: As can be seen from the equation (13), a=0.334, b=0.0015, substituting them in the equation (16), we obtain the 1977 wind velocity resilience coefficient α_{11}=2.1635; 1986 wind velocity resilience coefficient α_{12}=1.9609; and the wind velocity resilience coefficient during the period 1977-1986 $\alpha_1=(\alpha_{11}+\alpha_{12})/2=2.0622$.

Calculation of precipitation resilience coefficient: As can be seen from the equation (17), the key to the calculation of precipitation resilience coefficient is to determine the *k* value. The *k* value is determined by the soil moisture content transformed from the precipitation and hence it may be affected by several factors such as soil properties, air temperature and evaporation etc. Ejin Horo Banner, located in the transitional zone between desert steppe and forest steppe in China (Dong et al., 1988), has a humidity factor of 0.40-0.41. Humidity factor as an index of the climatic aridity is a comprehensive manifestation of the precipitation and potential evaporation (Ci, 1994; Ci and wu, 1997). We assumed that the humidity factor k=0.40. The precipitation during 1977-1986 was $P=(3.424+3.714)/2=3.569$. Substituting k and P in the equation (17), we obtain the precipitation resilience coefficient α_2=1.4276.

Substituting the wind velocity resilience coefficient α_1 and the precipitation resilience coefficient α_2 in the equation (10), we obtain the contribution of anthropogenic effect to the land desertification processes during 1977-1986:

$$K_1 = \left| 1 - \frac{2.0622 \times (-9.98) + 1.4276 \times 8.47}{-5.43} \right| \times 100\% = 56.33\%$$

Hence, the contribution of natural factor effect to the land desertification during 1977-1986 was $K_2 = 1 - 56.33\% = 43.67\%$

Discussion

The quantitative analysis of anthropogenic effect on the desertification process is a subject worthy of detailed study. This paper is only a preliminary exploration to this problem. Further study is needed to refine the analytical method.

A recent study found that the resilience coefficient has a fractal dimensionality. If the main factor affecting the desertification process is expressed as xi and human activity intensity M, let Y denote the desertification intensity in a given region, then we have the following functional relation:

$$Y = Mf(x_i) \qquad (18)$$

Where x_i and M are the function of time t.

Through differentiating operation and collation of the equation (18) we get:

$$\frac{dY}{Ydt} = \frac{dM}{Mdt} + \alpha_i \frac{dx_i}{x_i dt} \qquad (19)$$

To find out the resilience coefficient a_i in the equation and its fractal relation, it can be rewritten as

$$\alpha_i = \frac{\partial Y}{\partial x_i} \cdot \frac{x_i}{Y} = \frac{\partial Y / Y}{\partial x_i / x_i} = \frac{\partial \ln Y}{\partial \ln x_i} \qquad (20)$$

When the differential equation is used to define the fractal dimensionality, the dimensionality D can be calculated by

$$D = \frac{d \ln N(r)}{d \ln(1/r)} \qquad (21)$$

Clearly, the equation (20) and (21) have similar form and therefore the resilience coefficient contain the implication of the fractal dimensionality. This also shows that the precipitation and wind velocity used to measure the desertification degree have a certain irregularity and complexity.

For this reason, one can use other method to make a comparative estimation (Ai and Xu, 1988). In this paper it is calculated as a constant. The calculation of the resilience coefficient is a very important problem to assess the effect of human activities. Different calculation methods often give quite different results.

This is because the resilience coefficient is a constant under a quite strict conditions and it can be approximately viewed as a constant under specified conditions.

In addition, the selection of desertification indicators also needs to be further perfected. For example, the desertification area often cannot entirely reflect the desertification degree, furthermore, the precipitation and wind velocity at a measuring point cannot represent those of a larger region and the like. Of course, all these problems can be solved. In principle, the model reported in this paper can be used in a larger territory. First, it gives a simple calculation formula and the necessary data are easy to obtain. Second, the mathematical model is established based on the dynamic mechanism of desertification processes and therefore is easily accepted by experts.

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10

Relationship between Land Degradation and Sand Dust Storm Occurrence, Aeolian Sand Transport and Its Damages In East Asia during the Recent Years

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Introduction

According to statistics for the period 1949-1990 (Editorial Committee "Mitigation of Natural Hazard in Xinjiang for 40 Years", 1993), wind damage occurred a total number of 195 times and accounted for 108 deaths, 46,000 dead animal, 4,000 damaged houses, and a total economic loss of about 25 million US dollars, as shown in Table 1. The first and second highest damages (in terms of financial costs) are caused by floods and hail damage. The wind damage follows in at the third rank the total cost of damage and the 4th rank for total number of incidences. Therefore, this paper proposes that land degradation should be considered a result and, at the same time, cause of wind damage in the arid and semi-arid regions in China.

Table 1. Natural hazards in Xinjiang, 1949-1990

	Number of cases of occurrence	Loss		Number of houses destroyed	Total cost of damage
		People	Livestock		
		head	×1,000	×1,000	million US$
Earthquake	32	125	101	41	24.5
Drought	58	0	156	0	12.3
Flood	498	1,523	255	98	63.3
Wind damage	195	108	46	4	24.9
Hail damage	403	56	76	6	40.3
Cold wave & frost damage	217	212	7,773	2	6.1
Thunderstorm	19	15	0	0	0.0
Insects and disease	80	4	0	0	5.6
Fire	24	12	0	1	0.8
Total	1,526	2,055	8,407	152	177.8

The change of the occurrence frequency during the historical period is clear (Zhang, 1982; 1984; 1997), as shown in Figure1. A sharp increase was seen since the record half of 1980's, (Xia et al.; 1996 ; Yoshino, 1997). On the other hand, climatology of dust storm and its relation to human activities in Northwest China has been discussed recently (Yoshino, 2000 a and b). Agricultural land use has been particularly studied together with water use through irrigation, which has been increasing during the recent years. Based upon these changing tendencies, some aspects of the land degradation impact for the sand storm occurrence, aeolian sand transport and Kosa in East Asia are dealt with in this paper. In the last part of the present paper, economic loss and damages in the case of past violent sand storm are described. These are indirectly affecting the intensification of land degradation.

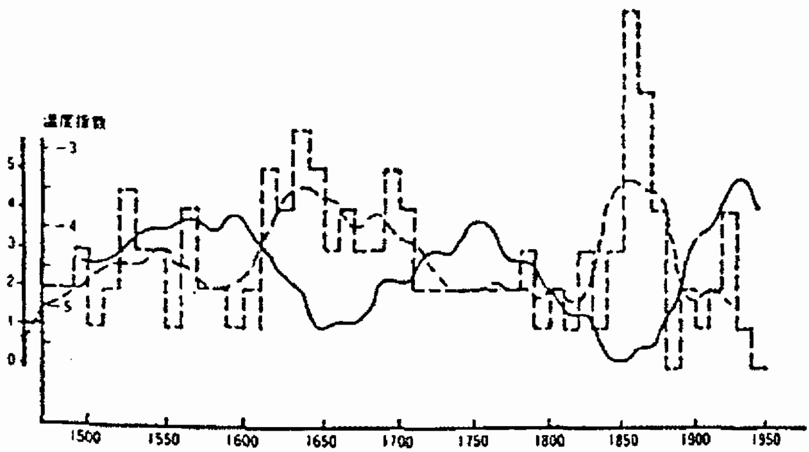

Figure 1. Long-term variations in the frequency of dust fall (histogram), its 5-yaear-running mean (broken line), and temperature index (solid line) in China, during the last 500 years (Zhang, 1982).

Year-to-Year Change of Occurrence of Aeolian Sand

Long-term change in occurrence of sand-dust storms at five stations in China (namely: Hotan in the southern part of the Taklimakan Desert, Minqin and Zhangye on the Hexie Corridor, Jurh in Inner-Mongolia and Beijing in the north plain) during the period between 1971 and 1998 are presented in Figure 2. This figure shows a clear decreasing tendency during the last 20 years except in Jurh and Beijing. That is, the number of days in Jurh was greater during the second half of the last 30-year period than the first half. Another striking fact is that the number of days was greater in Minqin on the Hexie Corridor, than in Hotan in the Taklimakan Desert during the first and second decade. On the contrary, those in Hotan were greater than that in Minqin during the last 10-year period. One reason for these is likely based in the different period of sharp development between these oases. For example, development of counter measures surrounding the oasis areas were undertaken differently from time to time and region to region.

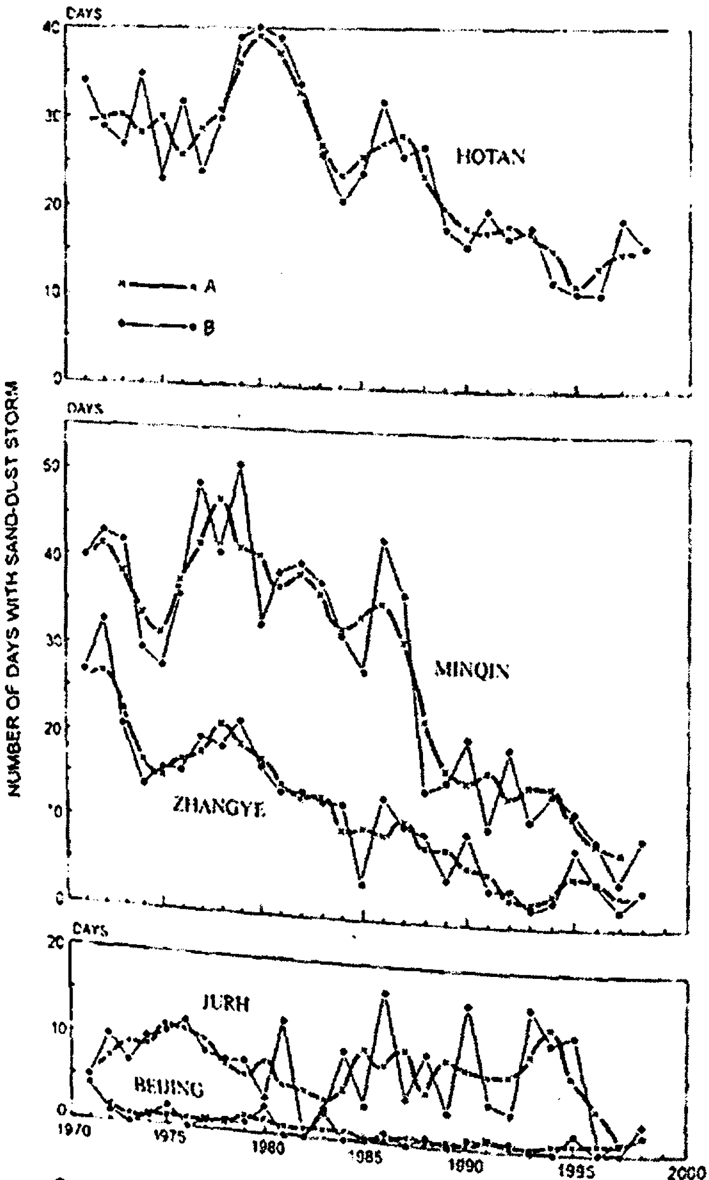

Figure 2. Year-to-year variations of number of days with san-dust storm (line B) at Hotan, Zhangye, Minqin, Jurh and Beijing. Thick line: 3-year-running mean (Yoshino, 2001)

A comparison of long-term variation during the last 30years among China, Korea and Japan is given in Figure 3. It is clear that the number of days with sand-dust storms in China has been decreasing as compared with a gradual increase in Korea and Japan. Roughly speaking, the period from 1976 to 1988 shows a parallel change in China, Korea and Japan. The contrast between China and, Korea and Japan, is markedly clear in the period from 1986 to 1996. Since 1997, it seems to have increased sharply in parallel in the three countries, even though the data from China are not presented in the figure.

In China, dust fall phenomena have been called "yudu" or "yumei" (same as Korea) and reported since around A, D, 300 (Zhang, 1982). Long-term changes reveal that dust fall frequencies in Northeast China had three prominent peaks around AD 1180-1300,1500-1710 and 1800-1880. It was concluded that dust falls were frequent in colder periods due to drier climatic conditions and strong cold airflow invaded from the Siberian anticyclone (Zhang, 1984; Fang, 1990). From this result, it is suggested that we are coming to a scarce period in the hundreds or several decades time scale.

According to a thorough study on the observation history in Kosa (Wada, 1917), falling dust phenomena has been recorded in old documents. Since 34 B.C., Yellow sand (Asian dust) was recorded as dust rain, mud rain, ash rain and snow-dust rain in Korea (Chun, 2000; Chun et al., 2000a; Chun et al., 2000b; Chun et al., 2001). The oldest record regarding dust was "dust rain" observed in A.D. 174 (Kim, 1983). These previous studies have concerned only with the climatological and meteorological causes and not to the relationship with human activities during the historical period. Further assessment of these historical records is needed.

Spread of Aeolian Sand in East Asia

According to a simulation study (Kai et al., 1988, 1998), the sand was transported by upper westerlies from the Tarim Basin to Japan over a period of 5-6 days. On the other hand, it took 2-3 days from the source region of the Gobi in Mongolia to Japan.

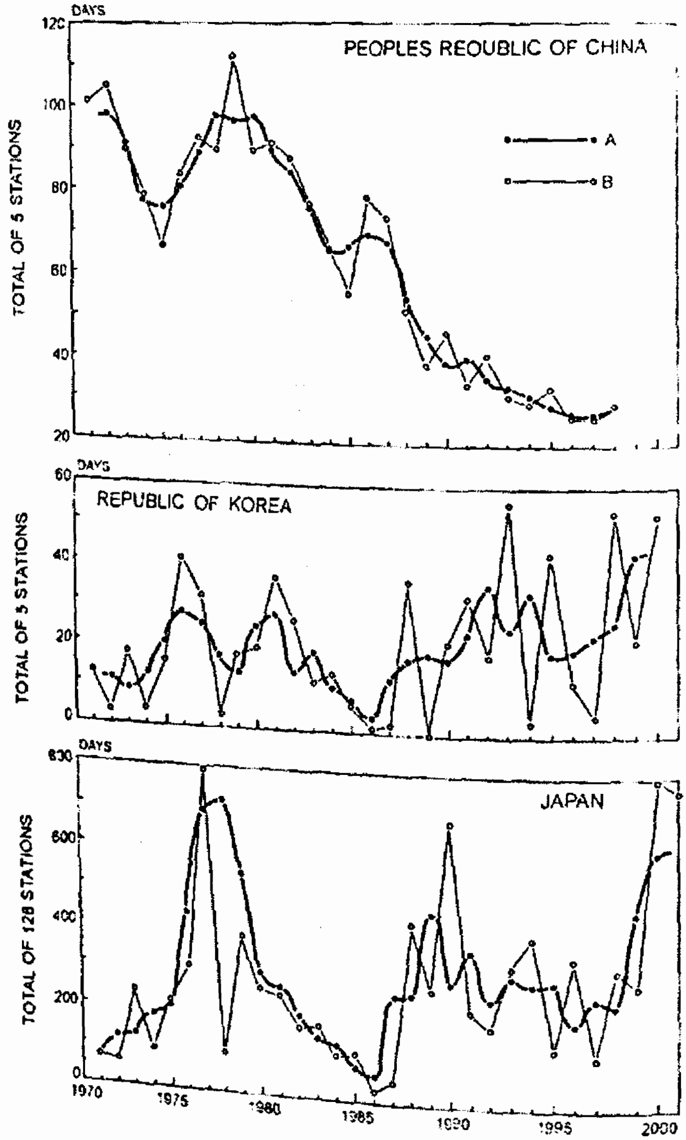

Figure 3. Long-term variations in total annual number of days with san-dust storms at 5 stations in China those with Korea at 5 stations in Korea, and those with Kosa at 128 stations in Japan, 1971-2000 (thin line B). Thick line A is the 3-year-funning mean (Yoshino, 2001).

Especially strong Kosa and suspended dust were observed nine times in Beijing in the spring of 2000. It was observed first in the daytime of the 3rd of March. Then, from evening of the 17th to midday of the 18th of March, it appeared again. Further, on the 22nd to 23rd and on the 27th of March and on the 3rd of April, it was observed. The most serious case happened on the 6th April. The area with Kosa and suspended dust spread over almost whole territory of China.

The average number of days with Kosa in Korea increased during the last 10 years, 1991-2000, to 4.5 days. Against to the decreasing tendency in China since the year around 1980. But in the spring of 2000, the number of days with Kosa was 9.2 days. In particular, dust seriously spread over the whole area of Korea during 23rd and 24th March, 2000 (Ryoo, 2001). The reasons why it was so striking this spring, were:

a. the land (soil) condition in the source region was particularly dry owing to scarce precipitation after winter;
b. the cyclogenesis was frequent near the source region; and
c. the upper air stream was formed in a good condition to transport the dust from the source region to the Korean peninsula.

NOAA observed the Kosa area over the Korean peninsula on the 6th of March, which arrived in Kagoshima, southwestern Japan, on the 8th of March. Again, a clear Kosa air mass came over the Okinawa area, southwestern Japan. The total number of days at 128 stations with Kosa was the highest maximum, 794 days, in Japan for the last 30 years. Thus the Kosa of 2000 was the worst case in Japan.

In Figure 4, a comparison of the Kosa area sequence is given. From China, the strongest cases (the largest areas, $1{,}310\times1{,}000km^2$) reached Korea in 0-1 day, but take 1-2 days in stronger cases (broad areas, $490\text{-}560\times1{,}000\ km^2$). The weak cases (relatively small areas) take 3-4 days in general.

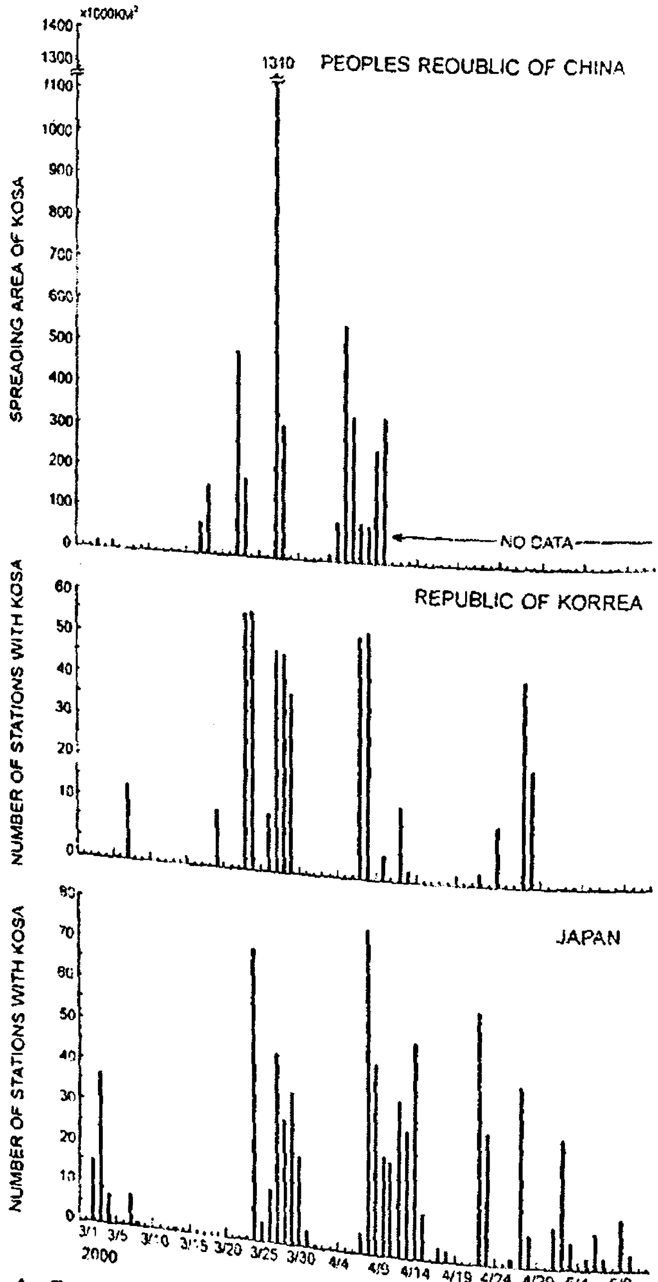

Figure 4. Sequence of total spreading of Aeolian sand in China and the total number of stations with Kosa in Korea and Japan from March to April, 2000 (Yoshino, 2001).

These tendencies are also observed between China and Japan. For example, in the case on 27th March, the peaks in China, Korea and Japan occurred on the same day, but in the case, when the peak in China occurred on 5th April, the peak with 59 stations in Korea appeared on 8th April, the peak in Japan appeared on 8th April.

As has been pointed out in the early 20th century, frequent and strong cyclogenesis in the source region in one of the main causes of sand dust storms and Kosa (Wada, 1917). Zhang (1982, 1984, 1997) described that the cold air invasion from Siberia is a causing factor to increase the number of Kosa, as mentioned above. Takemi (1999) described structure and evolution of long-lived squall line in Northwest China in the case of 5th May, 1993, which was one of the most severe sand-dust storm during the recent years.

These are combined into one meteorological process: increased frequency of cold air invasion, intensification of cold front activity and formation of long-lived severe squall line in the source regions of Northwest China.

Impact of Human Activities

In order to study on the relationship between the human activities and desertification in the Taklimakan Desert, collection of data on the agricultural landuse in the oases was tried by interview with the farmers. In 1993, field studies were carried out in the areas of Hotan and Qira in the southwestern part of the Desert and, in 1994, in Korla, Aksu and Kashi in the northern and western parts of the Desert. The question items of interview were: family structure, living history, house planning, area for house and cultivation, number of animals, cultivation/harvesting and production of crops, irrigation, ground and well water, fuels, damages by wind/ flood/ salinization, income from agriculture and side-works, health and living conditions, traffic/ transportation conditions and so on. Main results obtained are (Yoshino, 2000a, b):

1. The farmer's income in the southern part of the Desert is very low, as compared with those in the northern and western parts.
2. Farmers in the southern part have to use wood fuel from the desert, because of the high market price of coal.

3. In severe cases, the farmers go into the desert to collect firewood more than 130km from the oases by donkey-coaches.
4. When family members work on the side for additional income (carpet making, for example), they can use coal during the winter. Improvement in the economic condition of farmers may result in reducing amount of destruction and over-cutting of vegetation in the desert.
5. In the northern part of the Desert, no serious desertification was found.
6. Salinization, however, is serious in the northern part, because the inhabitants utilize enough water for irrigation.
7. When the fields for wheat or cotton are salinized, the farmers use them as rice paddy field by irrigation for 2 years. After that, they cultivate cotton again.
8. Accumulation of salt in the lower-most courses of rivers has been not yet considered in the Desert as a whole. The expansion of cultivated areas using a lot of irrigation water may result in serious land degradation problems in the future.

It is suggested therefore that one important issue for land degradation is the water use (water demand, water supply and water conservation) problems in the oases.

In Figure 5, the relationship between the cultivated land rate (cultivated area/total land area) and the irrigated land rate (irrigated area/total cultivated area) is presented. It is very interesting to note that the in the Northern Fringe oases the irrigated land rate is almost 100% until the cultivated land rate reaches up to 4% and then it decreases sharply in the regions with the cultivated land rate greater than 4%. In contrast for the Southern Fringe, the irrigation land rate is 80-85% in the drainage regions less than 2% of the cultivated land rate; then it shows a sharp decrease in the drainage regions more than 2%. This situation depends on the available water amount: water from the Tianshan Mountain Range can be utilized more as compared with that from the Kunlun Mountain Range. The second point to be noted is that the cultivated land rate has an upper limit according to the irrigation conditions.

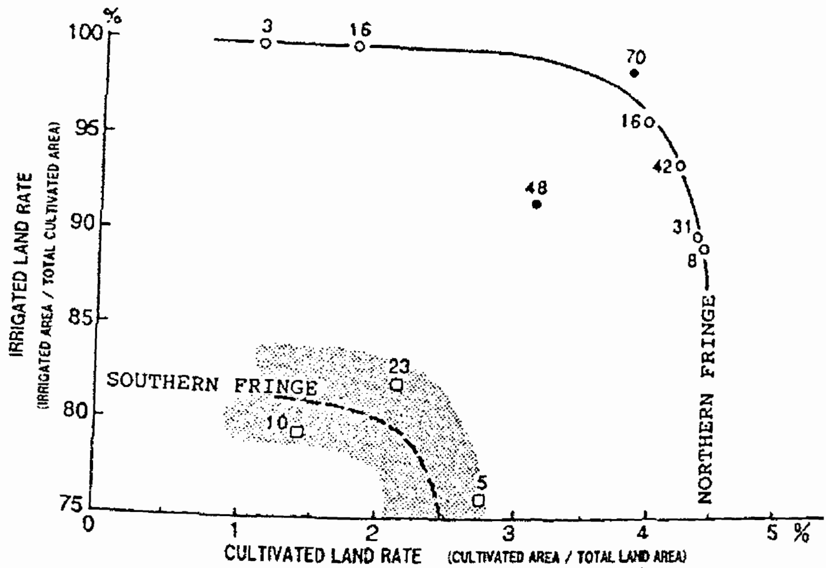

Figure 5. Relationship between cultivated land rate (cultivated area/ total land area) and irrigated land rate (irrigated area/ total cultivated area) in the oases in the Taklimakan Desert (Yoshino, 1997).

In the drainage regions with the cultivated land rate more than certain value, irrigation is no more sufficient which means that there is an increase in land degradation.

According to Zhu (1984,1990), the causes for desertified land formation or desertification in North China during the modern age is shown in Table 2 as percentages. From this table, one can understand that the over-cultivation (23-25%) plus the irrational utilization of water resources (8-9%) makes 31-34%. This means that the problems discussed in Figure 5 are related to about one third of the causes for desertification. Here, the area of desertification is defined as a region in which 5% or more of the areas is occupied by desert-like features (Zhu, 1984, 1990).

Table 2. Percentage of causes for desertified land formation or desertification in North China in the modern age

Causes	Desertified land in North China*	Desertification in the Northern Territory of China**
Over-cultivation	23.3%	25.4%
Overgrazing	29.4%	28.3%
Firewood collection	32.4%	31.8%
Construction of factories, mines, cities and roads	0.8%	0.7%
Irrational utilization of water resources	8.6%	8.3%
Advance of sand dunes	5.5%	5.5%

Notes: Data source for *is Zhu (1984) and ** is Zhu (1990).

The economic development and land degradation of oases in the Taklimakan Desert has been studied for the period of available data, 1988-1993 (Liu and Yoshino, 1997). The analysis led to the conclusion concerning to the agricultural land use, grain yield, change of population and desertification as follows:

1. Recently, the gross productions of agriculture, forestry, animal husbandry and fishery have been increasing greatly. Especially in the northern part of the Taklimakan Desert, the gross yield of agriculture raised markedly between 1988 and 1993. In the oases of the southwestern and southern parts of the Taklimakan Desert, increases of cultivated and sown areas are relatively less than increase of population. So, in spite of increases of the grain yield area and total areas of cultivated and sown lands, increase of grain yield per capita is only a little. The total amount of the other agricultural production increased greatly. For example, the gross production and per capita yield of cotton are the largest in China.
2. The cultivated area has been increased by reclaimed wasteland. But, on the other hand, the cultivated areas are decreasing due to desertification and changing land use for forestry, animal husbandry, housing and so on. It is clear that the cultivated areas should have to increase in accordance with increasing rate of population. Ecological and environmental problems in the oases, which are deeply related to this discrepancy, are different in the northern,

southwestern and southeastern parts of the Taklimakan desert, respectively.

Figure 6 shows the decreasing tendency of newly cultivated areas per year. And Figure 7 shows also decreasing tendency of abandoned cultivated land areas or the cultivated land areas changed to other purpose such as public and residential areas.

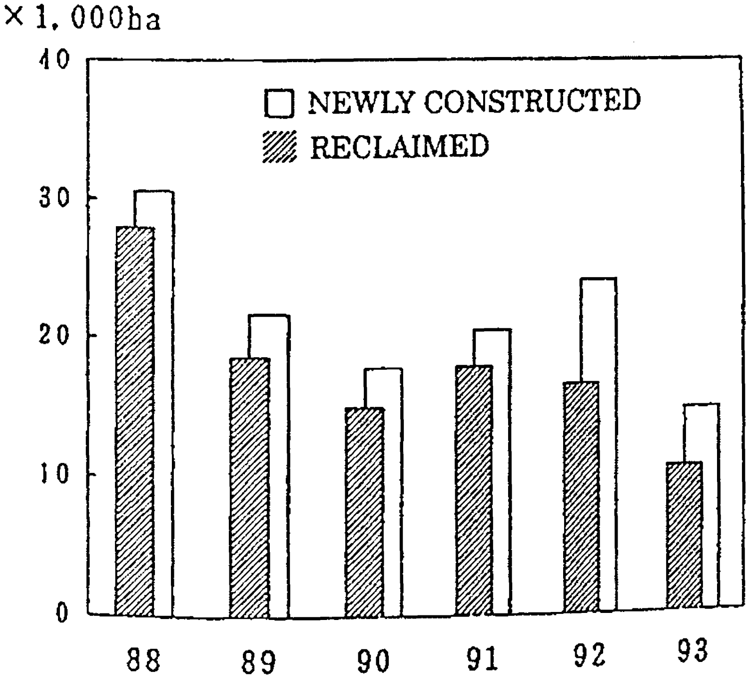

Figure 6. Change of newly constructed cultivated land (white) and reclaimed cultivated land (shadow) in the oases in Taklimakan Desert (Liu et al., 1999).

On April 15-19, 1998, violent dust storm, whose intensity was rare in the history of the Xinjiang region, was occurred. It prevailed for 4-5 days, but the strongest on April 17/18. For example, the maximum air temperature was 33°C, maximum ground temperature was 50.5 °C, and minimum air humidity was 34% in Changji on April 18. The observed maximum wind velocity of 38-40 m/sec was occurred at Qitai, Mulei, Qijiaojing and Balikun in the afternoon of 18th April (The Investigation Group of Duststorm, 1999). The damaged regions were very broad and it caused huge amount of damages on agriculture, industry, traffic, building,

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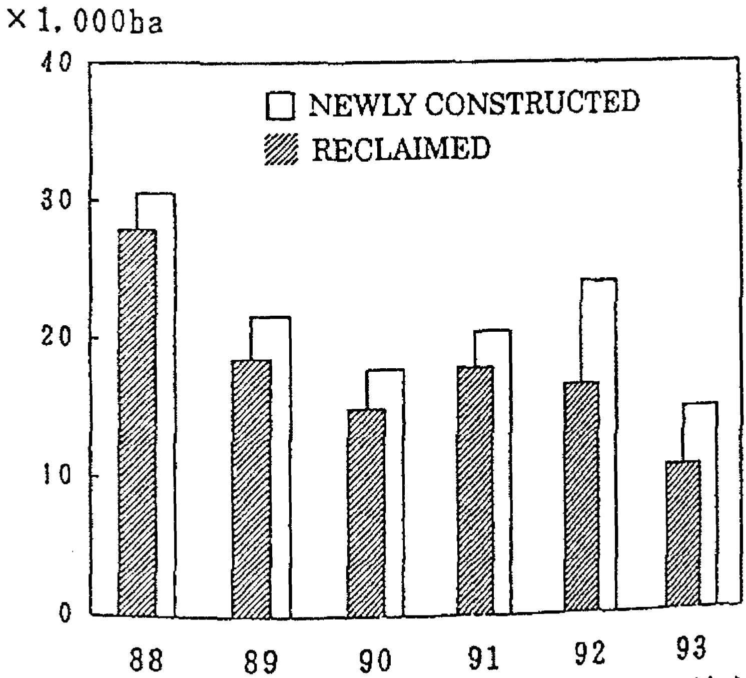

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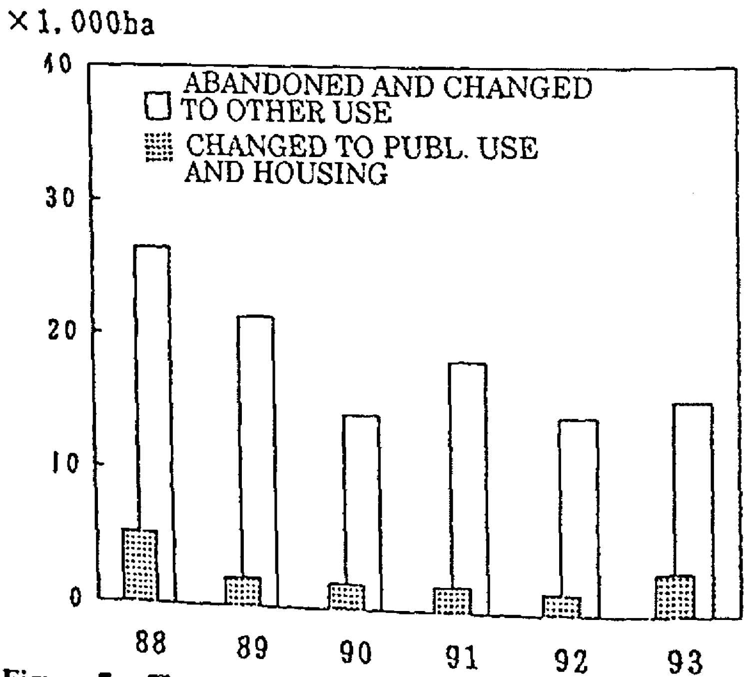

Figure 7. The cultivated areas abandoned or changed to other purpose (white) and the cultivated areas changed for public use or residence (shadow) (Liu et al., 1999).

Conclusions

In China, the decreasing tendencies of dust storm occurrence is obvious during the last 30 years. The period from 1976 to 1988 shows a parallel change with higher frequency in China, Korea and Japan. This may be related to the higher frequency of El Niño years. But a different tendency is shown in the period from 1989 to 1996. Since 1996 or 1997, a sharp increase is clear which may have been affected more by human activities with La Niña conditions in 2000. During the last several years, increasing trend is clear in East Asia. The worst case occurred in the spring of 2000. From China, the strongest cases with broader Kosa areas needed 0-1 day to reach Korea, but 1-2 days in medium cases and 3-4 days in weaker cases. The relationship between land degradation and Kosa should be studied further in particular for the past decade and future trand.

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11

Studies on the Structural Characteristics and Dynamic Change of Ecological Layer near Sandy Land Surface

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Introduction

Desertification is one of the most important problems for environmental integration in the northern parts of China. The general focus of this study is on understanding the reasons and mechanism of desertification development and countermeasures of desertification control. The occurrence and development of desertification and sandy storms results from the combined interactions of various factors in the natural environment. These are related to physical constitute, structure feature of soil, and species and structure of vegetation, and the changes of meteorological factors and boundary layer of atmosphere, and so on. So the interactive relationships of soil, vegetation and atmosphere, in particular the vegetation structure and ecological process near soil surface is the key issue for research on desertification and sandy storms.

Research on Status Quo

There are numerous research studies on the processes, causes and dynamic mechanisms of desertification. These studies focus on many different subjects including natural geography, pedology, plant ecology, meteorology and so on, in which the structural characteristics and changing law of ecological layer near soil surface is gradually accepted as the main problem for explaining clearly desertification development.

The structure of the ecological layer near soil surface is composed of the top layer of soil, vegetation layer and air layer near land surface, in which natural factors are much more active. So the vegetative growth and changes in physiological ecology of vegetation have a great role in the materials exchanges and energy flow near land surface. Ecological research combined with the related research of natural geography and meteorology on the interaction and parameterization in land surface process are getting much more attention.

The typical regions of desertification occuring in China include Kerqin sandy land, Mu Us Desert, Ejina Oasis, Hexi Corridor and so on. Most of these desertified regions occur seriously in the cross belt between farming region and pasturage region in semi-arid area.

Due to the acute changes in the natural environment of these region, the cycle of vegetation ecological system will greatly affect material exchange and energy flow near land surface. Especially in the case of vegetation destruction, the structure and function of ecological layer near land surface are closely related to the movement and leap of sandy dusts or sandy grain, and the formation of desertification and sand storm.

Reserch Contents and Achivements

The research studies on the structure, function and processes of ecological layer near land surface were developed over the past ten years. The major research findings for each of these three research areas were as follows:

Research on the Structural Characteristics of Ecological Layer Near Land Surface

The structural characteristics of ecological layer near land surface were affected mainly by plant species and plant growth and development, which were composed of the constitution, space structure and dynamic changes of vegetation. The growth of desert vegetation is presented in Table 1. The results showed that the density of vegetation in desert region was an important parameter for determining the height and coverage of vegetation.

Table 1. The growth of vegetation (Artemisia ordosica) in desert region.

Growth	Height cm			Coverage %			Length of new branch cm		
Density	25	35	70	25	35	70	25	35	70
1989	43	58.8	45	11.3	15.7	8.6	41	55	29
1993	55	58.2	40.4	20.3	26.7	22.3	30.6	40.6	24.6
1997	62.7	71.1	48.9	24.9	27.2	26.7	31.3	30.2	29.8

According to the above information, we know that the structure of vegetation is the basis of explaining clearly the dynamic mechanism of ecological layer near land surface. For this, we need to further study:

a. the components and changes of vegetation;
b. the horizontal and demensional structure of vegetation; and
c. the effect of vegetation structure on the movement of sandy grain near land surface.

Research on the Function of Ecological Layer Near Land Surface
The function of ecological layer near land surface was mainly composed of material exchange and energy flow, in which the changing laws of water and heat near land surface, especially understanding the effect of vegetation on water and heat change, were mostly carried out during the past ten years.

The major factor in desert environment is water, which includes precipitation, soil humidity and water stored in plant body. Water relationships between plants, soil and air play an important role to the functions of ecological layer near land surface. The following figure shows the relationships between precipitation and water consumption of desert vegetation.

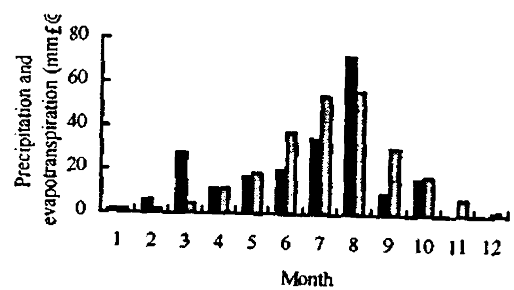

Figure 1. The relationship between precipitation and vegetation evapotranspiration (Artemisia ordosica).
(Note:■--precipitation, ▪--vegetation evapotranspiration)

Further research studies on this component should include the following:

a. the control of vegetation evapotranspiration;
b. the effects of plant growth on soil water; and
c. the relationship between status of humidity and heat near soil surface and formation of sandy materials.

Research on the Dynamic Model of Ecological Layer Near Land Surface
Research studies on the dynamic model of ecological layer near land surface were composed of determination of key parameters, establishment of appraising system and parameterization, and monitoring the ecological process near sandy land surface.

The above research studies are a cross-cutting theme between physical geography and ecology. Furthermore, many new technologies and methods, for example, inspection on charateristics near land surface by secondary planet, emulation of plant growth process by computer and so on, will be used in this field of investigations on the desertification processes.

Future Research

The research studies on the structure, function and changing law of ecological layer near land surface, especially in desert region, are now receiving much more attention. Only through fundamental research on the ecological layer near land surface, the cause and strategy for desertification control could be explained and put forward.

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12

Human Impact on the Land Degradation in the Kyzylkum Desert: Ecology, Dynamics and Conservation

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Desert Ecosystems

Uzbekistan, in the Central Asian region, is a landlocked country covering 447,400 km^2. Two-thirds of its land consists of steppe, desert, and semi-desert terrain with the remainder as fertile valleys where there are abundant natural resources—principally: oil, natural gas, gold , polymetals, and so on.

The Uzbek desert ecosystem covers the Kyzylkum, the Ustyurt plateau, the Karshi steppe, as well as, the separate sites in the southern part of Uzbekistan and the Fergana valley. Special conditions are found in the hilly and low-mountain areas of Kyzylkum, such as Kul'dzhuktau, Muruntau, Nuratau, Auminzatau, Bukantau, and Tamdytau. Here the eastern hills of the Kyzylkum and the Ustyurt plateau, display a unique natural landscape of complex ecological niches where the richest desert fauna and flora biodiversity is found.

The Uzbek "Chul" are gently rolling low lands with elevation between 100 to 500 m. It encloses a heterogeneous environment comprised of sand dunes, gypseous flats, clay and solontchaks depressions. It undergoes extreme, continental, arid conditions, limited and unreliable winter precipitation (Mean Annual Precipitation = 100-180 mm), a high level of evapotranspiration, extreme daily, seasonal and annual fluctuations of air temperatures, soils with high salinity and gypsum content, and finally as a result of all theses extreme conditions, it has a sparse, but diverse, vegetation cover.

The main sandy areas are:

a. The *Kyzylkum* ("the red sands"): It is located between the two largest rivers of Middle and Central Asia, the Syr-Darya to the east and the Amu-Darya Rivers to the south and southwest. These two rivers spring from the massive mountain chains of the Tyan'-Shan, Pamir-Alay and Turkestan to the west and the southeast, respectively, and drain into the Aral Sea to the north west (please see Figure 1).

b. The *Sudunkli*, in the southern part of the Amu-Darya River and Kashka-Darya province.

c. The *Kattakum* desert, in the lower part of the Surkhandarya province in the southern part of Uzbekistan, extends into Turkmenistan and Afghanistan.

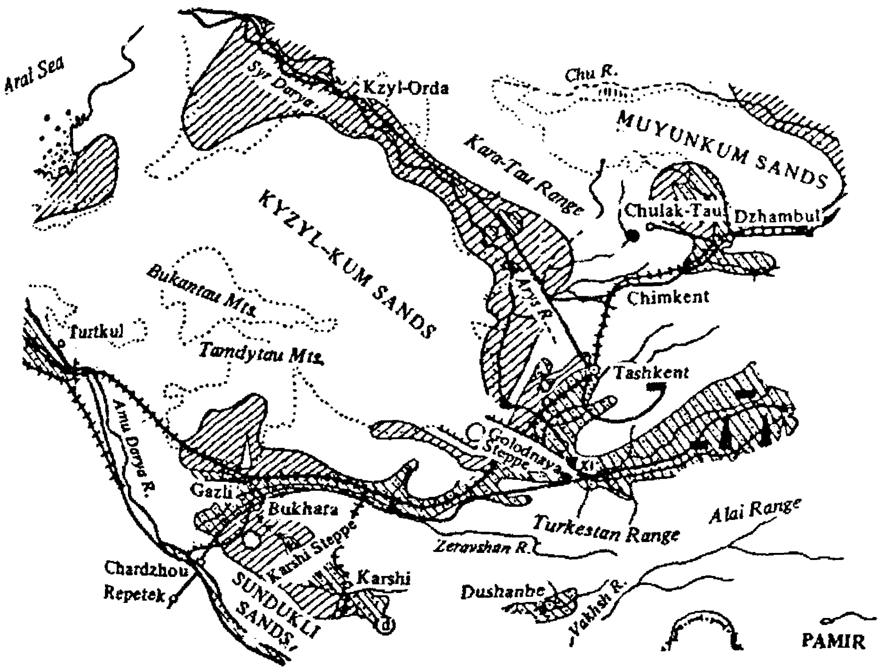

Figure 1. Map of the Kyzylkum Desert on the territory of Uzbekistan

In this paper, we shall concentrate only on the Kyzylkum. The eastern hills and low mountains (Nuratau, Kul'dzhuktau, Auminzatau, Tamdutau, Bucantau, Soultandag etc.) are distributed all over the Turanian lowland. Many solonchak depressions (Ayakagitma, Mingbulak, Beshbulak, Kulkuduk, Karakata, Karasugursk , Kukayaz) are located between sandy-loam/clay soil formations and large, sand-dune areas. These physico-geographical peculiarities immensely affect the unique flora and fauna of the Kyzylkum.

The distinctive features of the sandy deserts (versus other desert types) are due to the following sand properties: a high water infiltration rate, a mobile substrate, a significant condensation ability, and a low salinity. Moreover, the sandy substrate differs from other substrates by having a more favorable water regime that provides a long period of growth for the vegetation because of easily available stored water in the soil profile. Conversely, a number of negative aspect affect the plant cover on sandy soils such as sand mobility which limits plant establishment, poor soil structure and low organic matter. The soil can be easily loosened by the trampling of grazing livestock.

The poor management or destruction of appropriate native woody-shrubs / dwarf shrubs vegetation or forestry plantations in many arid areas of Uzbekistan is leading to land degradation with the development of wind and water erosion damage, preventing natural regeneration of rangeland plants. Shifting sands are one of the major problems of land degradation in the Kyzylkum Deserts. Shifting sand dunes in the Kyzylkum deserts are almost devoid of vegetation and makes up about 0,5 million ha (Kharin,1998). Such fragile ecosystems are very sensitive to land use practices. Grazing and trampling by livestock, agricultural use and mining industries destroy the vegetation cover and enhance sand mobility. Sand dune movement is a threat to irrigated farmlands, villages, railways, highways and others infrastructures.

Native species have the advantage of being highly adapted to the local edaphic and climatic conditions, which are characterized by having a strong seasonality factor.

The leading factors of anthropogenic disturbance of vegetative cover in the Kyzylkum deserts are:

a. agricultural land use (grazing, clearing of shrubs and undershrub);
b. hay making; and
c. technogenic influences (mining, construction activity, transport, etc).

Root Causes of Land Degradation in Uzbekistan

The human dimension of land degradation/desertification in Uzbekistan is considerable and often ignored. The majority of the dryland human population struggles daily with persistent poverty in their struggle to scrape a living from a harsh environment where productivity is low. In addition, traditional technologies have not kept up with the present rate of population growth nor the increased demands for food, fuel and shelter. The end results are entrenched poverty and malnutrition. The possibilities for creating new jobs has essentially disappeared. The problem of unemployment is especially acute for the rural population. Approximately nine million people, or approximately 45% of the population, live below the "poverty level." Unable to survive with scarce land and water resources, these poor people are often forced to become environmental refugees that migrate to neighboring lands and urban centers in search of relief, employment and refuge.

The root causes of the environmental problems are often located in a non-wilderness sector, such as agriculture or industry. It is useful to distinguish between 'drivers of change' and the subsequent actions in response.

There seem to be three major drivers of change:

1. The perceived threat to Uzbekistan national security because of low population density in the strategically important western border regions. Massive relocation schemes have uprooted millions from their homes. At the present time, there is a strong migration of the population from southern part of Aral Sea territories and in past decades, especially from Karakalpakstan's densely populated area.
2. Revolutionary zeal that translated into an urge to colonize the sparsely-inhabited "wastelands" and develop new sites for food production to meet the post- Second World War demands. In Uzbekistan the fight to tame the nature has been featured as a constant theme, born of the Soviet philosophy.
3. Economic imperatives and the need for more food to cope with the rapidly growing human populations were key factors.

These three mentioned drivers were translated into policy initiatives that led to the present day environmental crisis like the well known eco-disaster of the saline lands around the receding Aral Sea.

Land Degradation

Land degradation means different things to different people, and it is inappropriate to consider land simply as either degraded or not degraded. Severe degradation has undoubtedly occurred as evidenced by the lack of productivity. There is clear need to re-consider the definition of land that is affected by desertification (land degradation induced by a combination of human actions and climatic extremes).

Degradation is an ecological issue occurring when ecological characteristics or processes are changed and the integrity of the ecosystem is threatened or lost. It is related to changes in the land, the vegetation and the hydrologic regime, which make it less capable of meeting its desired uses. And, results from the interaction between vegetation and soil type, hydrology, climatic variability and land use pressures.

There are various degrees of degradation (degraded but recoverable degraded and beyond economic recovery and various types of degradation such as loss of soil (erosion), soil structural decline; chemical degradation (pollution, salinity) or loss of vegetative cover and biodiversity loss. The degree and type of degradation, and the region in which it occurs should all be taken into account in making assessments or comments on degradation .

As is shown on the Figure 2, land has a variety of users. It is critical that all users are involved in the effort to control land degradation. To concentrate only on farmers and herders would be a big mistake. Urban expansion, infrastructure development (roads, railways, airport, canals, powerlines etc), mining,mineral exploration, and water resource developments are just a few of the land uses that also need to be considered. Each has the potential to degrade the land and make desertification control more difficult. Uzbekistan has a special problem in dealing with hyper arid areas such as Central Kyzylkumes.

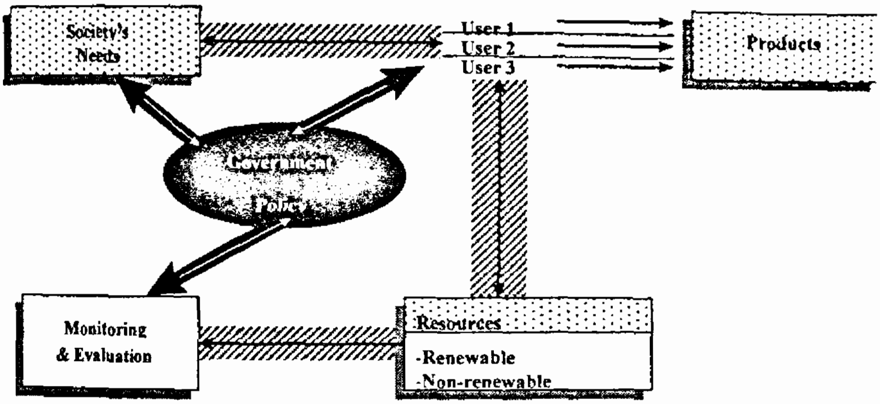

Figure 2. For each tract of land there is often more than one land user (farmer, miner, urban dweller etc). Each user draws from the resource base as it attempts to cater for society's needs. Each is affected by government policy. Monitoring and evaluation has a significant role to play in shaping policy and in protecting the resource base.

There is firm evidence that conditions within the core areas of Kyzylkumes Desert are getting worse and that some remedial effort is warranted to protect the biodiversity, urban settlement, resource extracting and communication links.

Monitoring systems are designed to gather more information on changes in the condition of land and the welfare of the people, but this raises the question of what should be monitored, how and by whom? Consideration should be given to the purposes of monitoring and issues such as intensity of monitoring, the balance between collection of data of sufficient detail to be meaningful, and the cost of monitoring.

Land managers, regardless of land use, require information on the impact that various types of management have on environmental and economic parameters. Whilst some land managers have gained considerable information through experience, there is a need to define the information requirements for all levels of land users. Information on environmental and economic performance is not freely accessible (and therefore difficult to evaluate). However, it is difficult to build up a satisfactory picture across all regions from the information currently available. Not only is this information necessary for land users to facilitate suitable management, but also for land administrators and policy makers to allow development of policies and programs appropriate to Sustainable Human Development objectives.

Historical Perspectives on Land Use Changes

Human intervention has long been a factor in the evolution of Uzbekistan's landscapes. In some regions of Uzbekistan's arid zones the roots of land degradation "goes down into a long history." Degradation had its beginning with the Neolithic and Bronze Ages, and now, many years later, it has expanded into the areas of Kyzylkumes Desert, which are now the most affected land degraded areas. They are populated, for the most part, by nomadic people of ethnic minorities, whose main use of the land base was as herders grazing their livestock on relatively abundant rangelands (Vinogradov et al., 1975). Farming activities (the system of sovkhozes (state farms) and kolkhozes (collective farms) commenced in the mid 19th century to the beginning of the 20th century in many arid and semiarid regions with an influx Russian colonization politics. In fact, then as today, much of the land being farmed was and is unsuited to that activity. Thus, the land conversions and subsequent degradations were gradually aggravated as result of increase in livestock and human populations .

Industrial development of Kyzylkumes desert was started mainly in 1958 with the Navoi Mining and Metallurgical Complex (NMMC), located some 300 km southeast of Uchkuduk (Central Kyzylkum). Large-scale industrial development of the gold mining, gas-and oil extracting and processing in the southeast and central Kyzylkums, for the last 15-40 years, have aggravated the land degradation of these territories. Tailing piles of ores below industrial grade, that were formed during the process of the deposits' development. The open and underground ways, the underground leaching (UL) mines and the tailings of the hydrometallurgical plants that processes uranium ores and technological solutions of (UL) are considered one of the main sources of environment pollution of the Kyzylkumes. Uranium production in the Kyzylkum area peaked in the 1980s when 3700 to 3800 tU/year were produced. The mine taillings of radioactive waste deposits (as well as the dumps of uranium ores below industrial grade and the mining of underground leaching areas) situated on the left bank of Zerafshan River near Navoi city is also dangerous for the ecology of the region.

More than 30 years of uranium production-related activities by NMMC have impacted Kyzylkumes's natural environment. This includes the areas affected by conventional mining and processing of uranium ores, as well as the operation of in situ leaching facilities. In addition to the areas directly affected by these activities, there are surface accumulations comprising and estimated to be 2,424,000 m^3 of sub-economic uranium bearing material. The uranium content of this material is estimated to be 2-5 mg/kg (0.002 to 0.005 percent U). This is in addition to the 60 million tonnes of tailings located near the Navoi Hydrometallurgical Plant and the ground water impacted by the in situ leach mining. The total area impacted by ISL mining is 13,000,000 m^2. The related contaminated material recovered from the surface of these operations is about 3,500,000 m^3 (Solodov, 1998).

High human impact (urban, industrial and agricultural activities, handicrafts and traffic) on the southern part of Kyzylkum deserts leads to the pollution of the sands and the irrigated lands with pesticides, nitrates, organic pollutants and various heavy metals (Goldshtein, 1997, Toderich et al, 1999, Tsukatani et al. 2001).

Sandy Soils Characteristics and Plant Relation

The Kyzylkum is mostly covered with recent eolian "Barkhanes" (barchans dunes) and lesser sand dunes, interspersed with "takyr" and "solonchack." The eastern and the western hills of the Kyzylkum and the Nuratau range represent a link between the mountain system of Middle and Central Asia and the Ural through the Mugodzhartau Mountains.

The ancient Zarafshan River and its now-dry tributaries spread its quaternary alluvial deposit on the southern Kyzylkum. To the eastern and the southern Kyzylkum, the clay and loessic deposits are dominant in the Karnab-Karshi steppe.

The above-mentioned geomorphologic elements of the Kyzylkum Desert determine the diversity of soils types: red sands, gray - brown steppe soils, gray - brown gypsiferous, takyr, salt-marsh (solonchak-alkali soils). Soils are characterized by low productivity with a predominance of carbonates and gypsum content. The humus content ranges from 0.5 in sandy desert and gray-brown sites to 0.7-1.2 % in the virgin and newly irrigated takyrs, widely distributed in South-Eastern Kyzylkum. As shown in Figure 3 much of the salt-affected land occurs in the Buchara oasis (South-East Kyzylkum), numerous solonchak depressions (Ayakagitma, Mingbulak, Beshbulak, Kulkuduk, Karakata, Karasugursk , Kukayaz) and in the technogenic industrial areas that are located between sandy-loam/clay soil formations and the large sand dunes areas.

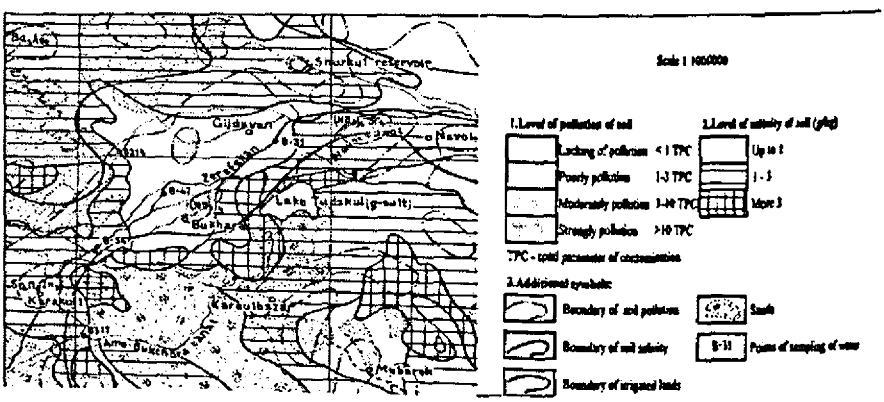

Figure 3. Extent of salinity and pollution of soils in South-east Kyzylkum region

A low productivity and high salinity (1,2-2,0 and rarely more than 3,0 % of soluble salt) characterize these soils, with a dominance of carbonates, sulfate, chloride and/or mixed types of salinisation. The predominate type of saline soils is sulfate-hydrocarbonate-calcium. In the Central Kyzylkum, which is less salinized, the sulfate-potassium-sodium (and rarely chloric-potassium-sodium) types occur frequently. In the last few years there has been a tendency for fast degradation of floodplain ecosystems of the Amudarya and Zerafshan Rivers delta –marginal territories of Kyzylkum desert. It seems that anthropogenic salinization of soils remains the main triggers for degradation of lands in the southern Aral Sea region (Treshkin, 2001).

The analysis of average values of trace element composition in the various types of soils of the Central Kyzylkum deserts show high levels of Hg, Cu, U, As, Zn, Mo, Ni, Sr, Co (Table 1). Coefficients of concentrations (Kk=Cf/Ck) of above-mentioned heavy metals exceeds 1.0. Soils contaminated with As, Zn, Ni, Mn, Cu, and Sr have been defined to be mostly toxic and widely distributed in sandy Kyzylkum Deserts. Nickel is of natural origin and in the soils it occurs in form the rich nickel-cobaltum rock types, particularly of Palaeozoic age. Concentrations of nickel in soils are in the ranges of 60-70 ppm. The mobility of As, Cu, Zn (along with other heavy metals and their accumulations) are highly facilitated by both chemical properties of soils and the aridity of the climate of the Kyzylkum Deserts.

It is noted that the technogenic pollution by heavy metals, organic pollutants is concentrated around mining and tailing waste deposit zones and is located exclusively in foothills areas of Kul'dzhuktau, Auminzatau, Tamdutau, Dzhemtau, Aristantau and Bucantau mountain ranges (Central Kyzylkum).

Table 1. Average values of trace metals composition in the soils of the Central Kyzylkum Deserts

Chemical elements	(C_k)', ppm in the soil according Klark	Average containing (C_f), ppm	Coefficients cf concentration (K_k)
Be	6	1	0.2
Cd	0.5	0.19	0.4
As	5	7.7	1.5
Hg	0.01	0.048	4.8
Pb	10	8	0.8
Zn	50	51	1.0
Co	10	8.1	0.8
Cu	20	57	2.9
Mo	2	2.3	1.2
Ni	40	40	1.0
Sb	-	1	-
Cr	200	55	0.3
Ba	500	400	0.8
W	-	4	-
V	100	89	0.9
Mn	850	340	0.4
Sr	300	190	0.6
U	1	2	2.0
Th	6	8.2	1.4

(Source: Vinogradov,1957; Malyuga,1963)

Tailing sand soils contaminated with cadmium, copper, iron, nickel, manganese, chromium, lead and zinc are colonized by plant and animal species that have developed strategies for avoidance of and/or tolerance to metal toxins. One possible avoidance strategy is for plants to prevent the uptake of potentially toxic metals. This mechanism is not strongly developed in vascular, arid-land plants, although tolerant plants may restrict metal uptake to varying degrees. The concentrations of some metals (indicated in the Table 1) were only unusually high in the accumulators plants.

Our experiments have demonstrated that only a restrict number of the Kyzylkum sandy/deserts species have the ability to translocate, to high concentrations, a wide variety of elements, such as: Fe (15-4170); Zn (9.0-50.0); Pb (0.1-7.6) ; Ni (0.0-3.7); Cr (0.1-50.0) ; Sr (0.0 –793.0); or trace levels (e.g. As (0.1-1.9); Co (0.1-2.7); Th (0.1-2.5); Cd (0.1-0.18).

A survey of much of the Kyzylkum halo-metallophyte flora has revealed a few species in Uzbekistan, mainly from genera *Salsola* (both annuals and perennial ones), *Haloxylon*, *Halothamnus*, *Kallidium*, *Anabasis*, *Tamarix*, *Artemisia*, *Peganum*, *Zygophyllum*, *Smirnovia*, *Poa*, *Allysum*, *Carex*, *Euphorbia*, *Frankennia*, and *Lycium*. The plant families most strongly represented are the *Euphorbiaceae*, *Tamaricaceae*, *Chenopodiaceae*, *Poaceae* and poorly *Asteraceae*, *Fabaceae* and *Cyperaceae*. However, future work is needed to:

a. select optimal genotypes from Kyzylkum desert flora and to initiate a program of it's seed multiplication;
b. determine the mechanisms of their hyperaccumulation and hypertolerance; and
c. isolate the genes involved. It may then be possible to genetically engineer these traits into higher biomass crops by making them transgenic and make the process of heavy metal phytoextraction more efficient.

Conclusions

The high biological diversity of the Kyzylkum Deserts ecosystems is of significant scientific and practical value and requires restoration and conservation.

Two methods for biodiversity conservation are suggested:

a. restoration of lost ecosystems; and
b. establishment of a network of regional protected areas.

Restoration of natural ecosystems could be realized by artificial phytocenoses. The natural vegetation remaining on the sandy salinezed or contaminated lands can serve as a model for the creation of man-made ecosystems, as well as a source of seeds. Reintroduction of the vanished wild vegetation in suitable habitats will provide the formation of seed banks and the natural dissemination of vegetation.

Phytoremediation technology is a potentially valuable technique for dealing with heavy metals, which are the most difficult pollutants to remove from soils.

Some of the rarest halo- and metallophytes, especially those known from only a single site, are very vulnerable to the human effects (overgrazing, deforestation, waterlogging, land clearance, collection of fuelwood and herbal/medicinal plants). A single incident could thus eliminate a species completely. The establishment of a seed bank for species open to this threat should be seen as a high conservation priority. Improved information about the total distribution of hyper- salt/metal accumulator species would also help to assess the risk, to the Kyzylkum's desert plant communities, posed by continuing urban and associated development, including the use of mine waste areas for various types of recreation. The removal of the rarest species from the field for herbarium collections or of their seed for commercial exploitation as horticultural items or for phytoremediation trials, all constitute threats to the continued existence of the natural resource unless these activities are strictly and responsibly controlled.

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The Strategy for Soil Conservation Farming in Tajikistan

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Overview

Tajikistan is situated in the mountainous part of Central Asia. The total area of Tajikistan is 14 million ha, 93 % of it is mountainous. Agricultural lands account for 23% of the total area. Tajikistan as mountain country is characterized by vertical belts (please see Table 1). The climate is sharply continental with low air humidity, considerable fluctuation of annual and daily temperatures, minor quantity of precipitation and also long, hot, arid summer and short winter. Distinctive feature of soils in many vertical belts, as a whole in Tajikistan is the low content of organic matters and nutrients, very high erodibility, unfavorable reclamative status of soils that are limited by a poor maintenance of drainage system.

The path to democracy and market economy for Tajikistan has had many setbacks as well as political and socio-economic shocks. Developing a democracy from a turbulent past is a difficult and slow process. However, some positive progress has been made and many changes are visible. We established the private sector, multystructure land use system, free price system for agricultural products and there is a good economic activity. Compared to 1995, total agricultural production has increased. The international community has encouraged the efforts to move towards democracy and free market reforms by supporting several development projects.

At the same time during transition period to market economy Tajikistan faced with the numerous problems in agriculture:

- decreasing the yield of crops, especially cotton two times.
- increasing the area of eroded land.
- increasing the area of saline and waterlogged soils.
- content of organic matter and available nutrients in soil decreased.
- application of mineral and organic fertilizers decreased 10 times.
- desertification

The main reasons for the existing situation are:

- new farmers are short of investment for reclamation of soil.
- state land management.
- uncontrolled cultivation of sloped terrain, tillaging of pastures for grain production

Table 1. Area of natural zones in different regions of Tajikistan. (in km^2)

Group of Regions	Soil zones							Total
	Grey-earth Belts			Steppe: mountain-ous and forest	Sub-alpic	Alpic	High-mountainous and steppe-desert	
	Desert	Steppe-desert	Total					
Sygd	4166 / 17.2	5976 / 24.5	10142 / 41.7	4361 / 17.9	11.92 / 5.0	22.95 / 9.4	62.95 / 26.0	24269
Hissar and Vakhsh	5727 / 23.3	10210 / 41.3	15937 / 64.6	4618 / 18.7	25.78 / 10.4	15.69 / 6.3	-	24702
South-East	827 / 7.1	4835 / 41.7	5662 / 48.8	5697 / 49.0	256 / 2.2	-	-	11615
North-Eastern	–	959 / 5.0	959 / 5.0	5838 / 30.2	4076 / 21.1	6000 / 31.1	2441 / 12.6	19314
Badakhshan	-	-	-	370 / 0.6	6306 / 10.5	16539 / 27.4	37104 / 61.6	80319
Total:	-	-	32700	20884	14408	26403	45824	140219

About 90% of Tajikistan's rainfed agricultural land is located on sloping areas. Soil erosion, deforestation, over-grazing and salinization are perhaps the most serious environmental problems in Tajikistan today. These are several factors contributing to accelerated soil erosion, which include natural (irregular rainfall pattern, shallow soils, high slopes, fragility of soil material) and human factors such as abandonment of sloping land, deforestation, overgrazing. Other forms of degradation are the landslides, found in many areas throughout Tajikistan, greatly reducing not only the sustainability of agriculture but also the long term security of rural housing.

Saline soils of Tajikistan are located on the lowland and under the influence of arid climate, which accelerates evaporation in summer and causes salts to concentrate on the surface. Recently there is an evidence of increasing secondary salinization in many areas and the trend is continuing.

Awareness of the farmers about soil and water sustainability is very poor. The farmers have no awareness about soil erosion danger and about landscape sustainability. They do not know to how big danger is the soil exposed to when being left without plant cover threatening by rainfall aggression.

Now that the immediate needs of the country to ensure sustainable development are understood, the time has come to develop strategies and policies that address both production and environmental implications. Because of the lack of developed industries and infrastructure to implement the needed programs, a major thrust of future activities will be to fully utilise two resources - people and land - in the efforts towards sustainable development. To integrate these and prepare for challenges of the future, concomitant with privatisation, there needs to be a better integration between the socio-economic and biophysical factors of production. This requires strengthening research, delivery systems and development process.

Therefore, for optimizing soil properties, soil conservation and sustainable farming in Tajikistan we should grow or place agricultural crops according landscape and need of market. For new economical condition of decreases investments new crop rotation should be adopted. Reduction in use commercial fertilizers should be compensated by wider application of organic manures.

The flows of water may cause considerable soil erosion. For farmers, this means losses of both production and the farm natural resource capital. By stripcropping the farmer can minimize the risks and losses of soil and water (please see Figure 1). Cultivating wheat in the high slopes increases loss of soil and water compared with stripcropping of wheat and grasses or grasses and wheat or beans and grasses. This system of using slopes increases the quantity of organic matter in soil. Quantity of humus in the stripcropping treatments increased from 1,34 to 1,85%. Stripcropping approaches as the part of integrated land management can control soil erosion and improve the productivity of farming and conserve natural resources.

Mulching is an important technique for improving soil microclimate; enhancing soil life, structure and fertility; conserving soil moisture; reducing weed growth; preventing damage by impact from rainfall (soil erosion) and reducing the need for tillage. Mulching is very important technique for water harvesting, as shown in Figure 2. In the rainfed agriculture, good management of water is of great important, especially when rainfall is too irregular and unfavorable for growth conditions. Mulching with plastics and plant residues can improve water harvesting capacity of soil and growth of trees in the south of Tajikistan.

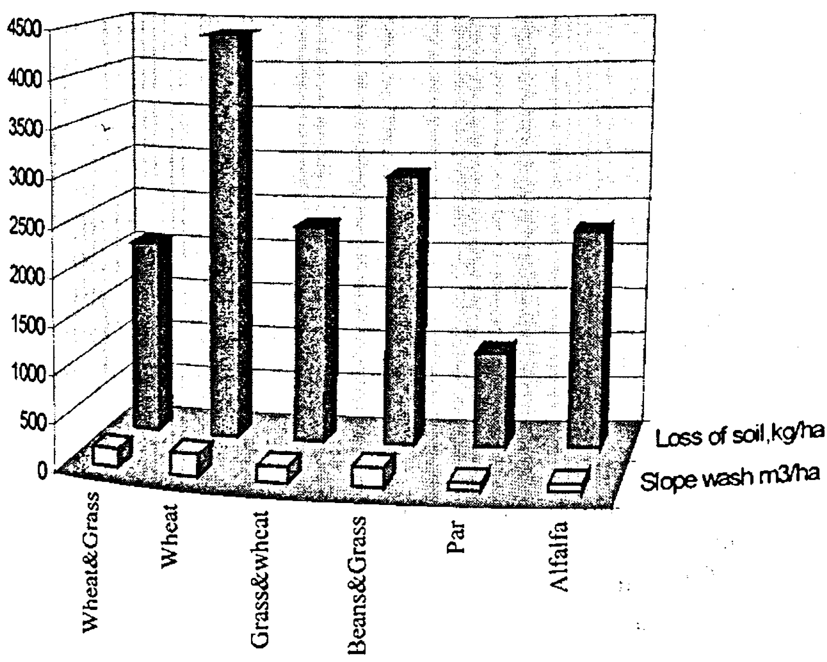

Figure 1. The influence of stripcropping on soil loss

In general, good vegetative cover of soil, protection from erosion, organic matter management and guiding the flow of excess water are the most important ways of conserving soil and increasing farming productivity.

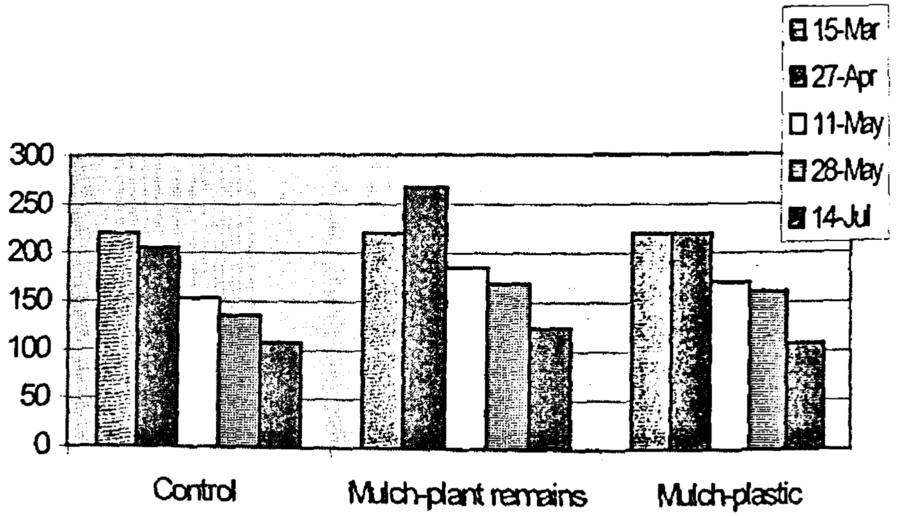

Figure 2. The influence of mulching on water harvesting capacity of soil

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Farm Water Harvesting Reservoirs: Issues of Planning and Management in Dry Areas

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Introduction

Water is the key to the development everywhere in the arid and semi arid areas. It is particularly critical in areas where water resources are scarce such as the dry areas of West Asia and North Africa (WANA). In these areas, almost all the readily available water resources are utilized for domestic, industrial and agricultural purposes. The share of agriculture is continuously decreasing while more food is needed to satisfy increasing demand. Under such conditions, the capture and the efficient utilization of every available potential water resources become essential.

Precipitation supports dry farming in the favorable environments of the dry areas (i.e. >300-400 mm annual) whereas it is not sufficient in the drier environments (i.e.<300-400 mm annual) for economical dry farming. Unfavorable rainfall characteristics, poor vegetative cover, soil surface conditions, and the absence of proper management cause the loss of over 90 % of the rainfall by evaporation or by runoff to salt sinks or areas unsuitable for development.

The most efficient and effective use of rainfall in this area can be achieved by integrating proper water harvesting (WH) techniques in the farming systems. Wide range of water harvesting techniques is used to concentrate rainfall in smaller target areas for beneficial use. One of the important WH techniques is collecting rainwater in small reservoirs at the farm for domestic and agricultural uses (Oweis et al., 1999). Small farm reservoirs have been built for long time in the WANA region. During Chalcolitic time, constructing small dams to divert part of the water into cisterns controlled floods coming from Jebal Al Arab in Syria. In the Roman and Byzantine times, many dams were built, some of which are still operational. Many other structures were reported to be still functioning in other areas of the region. Nabatians in southern Jordan harvested water in reservoirs dug in the rock since the 7th century BC (Oweis et al., 2001). They had carved the sandy rocks and collected every drop of water from these bare surfaces. Water was stored in excavated wells properly designed to eliminate evaporation. Other systems include building earth dams for large water collection and channeling water to flood the land for agricultural uses.

The importance of this method has been emphasized more recently because water scarcity is increasing and more attention is directed to developing drier environments. In this context, small reservoirs became increasingly popular in the Badia of Syria, Jordan, Tunisia and Morocco. It can be observed that, generally, they are built with little planning. Most of the stored water is lost in evaporation or seepage and frequently, structures are broken due to improper design or permanently filled with silt.

The authors, with the support of the University of Jordan and the European Union, initiated in the mid-1980's a research site in a typical area of the Jordan Badia (Muaqqar) to investigate the potential use and improved management options of small farm reservoirs and followed up on it since then. Three small earth dams were built across a wadi creating farm reservoirs. The reservoirs' water is used to irrigate research plots of field crops and trees at the University Station (JAZEPP, 1999 and Drolett et al.1997). The experiences gained from this work are immense. This paper summarizes these experiences and highlights the major issues to be addressed in the future.

The Target Area

The drier environments in WANA, usually called "steppe" or "Badia", are characterized by rainfall that is low, erratic, unpredictable and highly fluctuating with annual mean ranging from less than 100 mm to about 300 mm. Potential evaporation is much higher than that of rainfall and may exceed 2000 mm annually. Other water resources are scarce. Fossil ground water exists in some areas but is limited and costly to extract for agriculture.

Temperatures are high during the summer (>30°C) but may drop below zero in winter. Soils vary from place to the other but mostly calcareous or sandy, shallow at steep slopes and deeper at flatter slopes. They have been influenced by water erosion with surface crust widely developed restricting seed emergence and causing low infiltration and high runoff. Soil fertility is generally poor with low productivity. Topography ranges from flat to undulating with dense drainage system associated with the later. Vegetative cover is generally poor with sparse bushes and grasses due to land degradation and intensive human activities.

The area is mostly public land inhabited by nomads living from growing animal and grazing is their major activity. In areas close to the urban centers some settlement occurred with more defined ownership and intensive agriculture introduced at small scale.

Decision-Making Process for Building a Farm Reservoir

Farm reservoirs are usually formed by building small dams across a suitable section of the wadi or by diverting the runoff water to a natural or man-made depression. Availability of suitable site, adequacy of runoff and the availability of feasible options for use are the major considerations for deciding to build a reservoir (Frasier and Myers, 1983; Palmer et al., 1982). Site suitability is mainly determined by examining topographic maps. Geographic Information Systems (GIS) can assist in siting farm reservoirs (Vorhauer and Hamlett, 1966; Oweis et al., 1998). Evaluation of runoff adequacy is more difficult since flow records are rare in these areas. It may be determined by the farmer's long-term observations or by a specialist using a proper hydrologic model. Another preliminary consideration is the potential for developments upstream. Having suitable conditions, however, does not necessarily mean that developing a reservoir is the best choice. The choice of the proper water harvesting system should be made after a thorough considerations of all potential alternatives. Generally the farmer may be encouraged to build a reservoir under the following circumstances:

1. When water is needed for multi uses such as for drinking, livestock or environmental purposes.
2. When adequate and sustainable runoff is available. One should, however, carefully examine the possibility of potential upstream development over the reservoir life that might change the situation substantially in terms of runoff availability.
3. When the farmer has the capacity to manage the facility. It is common in the area that reservoirs are poorly managed due to lack of capacity and most of the stored water is lost while causing damage to the environment.
4. When no conflicting interests exist with other parties such as neighbors, environment and public that could not be resolved.

Selecting Reservoir Size: Small Versus Large Reservoirs

Most of the existing Badia reservoirs are built by the public sector and only recently individual farmers started to build farm reservoirs. Available public reservoirs are of relatively of large size (millions of m^3). Usually these reservoirs are built without sufficient exploration of all available options. Furthermore, they are built without proper planning for the economic utilization of the water and no consideration to the social structure of the nomads in this region. The water collected as a result is not used efficiently and mostly evaporates back to the atmosphere. Several reservoirs of this type are built in Jordan, Syria, Iraq, Tunisia and Morocco. Reports on these dams indicate very low water use efficiency. A better strategy may be is to build instead several smaller ones upstream. In this case reservoirs will be closer to the farmers areas as they distribute and accessibility will be easier. Also the utilization of smaller amount of water is easier and the design and construction and management are simpler. Improved environment and farmers benefits may be spread wider with a more equitable distribution.

One advantage of using small reservoirs is that dam design, construction and management does not require sophisticated knowledge of hydrology and that much of the precautions usually taken when working with medium- and large-sized dams are not needed for small ones. Designing a small earth dam mainly involves determining the type, size, and details of its body and spillway. The principles of designing small earth dams can be found in any design manual (Linsley & Franzini 1964). However, designing for simplicity and low cost are important for their adoption.

Management of Reservoir Water

The common practice in WANA dry areas is that the farmers store water during the rainy winter to be utilized in the dry summer. This practice seems necessary in rainfed areas where rain is sufficient to support rainfed crops in winter and/or when the water is needed for domestic or livestock use in the dry season. However, when water is mainly needed to support agriculture in the drier environments, the soundness of this practice is doubtful. We here argue that using the water in winter is far more efficient and beneficial than leaving it to be used in the dry summer. The rational and alternative options are discussed in the following section.

Maximizing Water Use Efficiency

In the drier environments of WANA, water not land is the most limiting factor to development. This essentially requires strategies different from those practiced in more favorable environments. Strategies to use this limited resource should be based on maximizing water use efficiency (WUE) in a sound agricultural systems. The term WUE is used here to mean the biologic as well a socioeconomic return per unit volume of water available. Options that maximize WUE need to be explored in order to optimize this practice. This includes determination of types of uses, extent of cultivated area, combination of crops, amount and timing of irrigation and other cultural practices. In this regard, two controversial issues arise:

a. The value of using the stored water in the rainy season as supplementary to rainfall versus delaying the use to the summer, or a combination of both; and
b. The benefits of adopting a no-risk strategy in managing the water in the reservoir versus a more liberal one.

The Mediterranean-type climates have the comparative advantage that the rainy season has low evaporative demand. This advantage if added to the disadvantages associated with losses of water associated with keeping the water to the summer it is argued here that using the water in winter is far more efficient than in summer for the following reasons:

1. Improving WUE involves reducing losses such as reservoir evaporation and seepage. This implies that water be removed from the reservoir and stored in the soil to stay minimum time in the reservoir. Such a strategy not only reduces evaporation and seepage losses, but also allows for greater chance to store more runoff water. Emptying the reservoir means higher rate of utilization, or storing it in other place. Water can be stored in the soil profile until used by the crop over the cropping season.

2. Evaporation is the major loss of the reservoir water. Controlling evaporation is very difficult, tedious and costly. However, evaporation is very low in the winter but rises fast after March or April. Total evaporation from the surface of the three reservoirs, built at the UJRFM, between 1st of Dec. until 1st of April is about 15000 CM. This loss equals to the evaporation of only one-month during the summer. Such information suggests that water should not stay in the reservoir until summer. Water may be stored in the soil profile before the high evaporative demand period starts and used by winter crops during the cooler season instead of losing it in evaporation.
3. The productivity of water used in supplemental irrigation of winter crops is higher than that used in full irrigation in summer (Oweis et al., 1997). Sharma and Helweg (1984) found that potential WUE of small reservoir used for rice in winter is 3 to 4 times higher than actual system WUE.
4. On wadies, the reservoir capacity can be much more than the physical volume. It is proportional to how many times one can fill it. One could, if necessary, empty the reservoir and store the water in soil profile to store more water when new runoff occurs. However, this practice can only be undertaken if water is used in winter. This issue will be discussed in a subsequent section.

Scenarios for Management

Accepting this argument still needs an optimization of the use. This leads to the second issue stated earlier regarding the risk in the management of the reservoir (Senga 1991). In this respect, two possible scenarios may be recognized:

1. *The Minimum Risk Option* (MRO): In this option, one determines the size and type of target use to insure fulfilling crop water requirements with assured water storage in the reservoir. The reservoir is used conservatively to irrigate small area not relying on receiving more runoff water over the season. Though the land area served will be small but the water availability is assured for the crops. The loss here is when more runoff occurs, the reservoir will be full and will not be able to catch the opportunity. Such loss to the farmer does not always mean loss to the water basin, but

from the farmer point of view, the opportunity to have more valuable water in that area is lost. This is particularly important if we know that most of the runoff water is lost to evaporation somewhere in the desert. This argument will continue to be valid until a comprehensive development is in place and all upstream and downstream waters are used optimally.

2. The Maximum Capacity Option (MCO): In this option, one empties the reservoir as soon as possible after it is filled and water is stored in the soil profile to ensure reservoir space for next runoff. The target area here will be much larger than described in the MRC option. More water can be stored and utilized, but the risk of not having additional runoff after emptying the reservoirs is real. It is true that the promotion of effective release conflicting restriction of release in preparation for drought but the availability of rainfall and early irrigation opportunity makes the risk of crop failure minimum.

Information on the runoff events, number and distribution, over the winter season is needed to assist the proper selection of the management strategy. Analysis of this type was conducted for UJRFM and resulted in the following (please see Tables 1 and 2):

a. It was found that the threshold for the occurrence of runoff in the Muwaqar catchment is 7 mm/day and the threshold amount to fill the three reservoirs is 13 mm/day. These numbers are conservative and correspond to the lower rainfall intensities in the area. Lower values of daily rainfall were found with higher intensities. These values were used to make the generalization possible. The analyses show that chances for runoff occurrence are very good until April after which it drops sharply.
b. Table 2 also shows the probabilities of having the amount of rainfall per day needed to fill the three reservoirs at Muwaqar. The 13-mm/day amount needed to fill the three reservoirs is 100% assured in December and the farmer can empty his reservoirs with no risk at all if occurred earlier. However farmer has a very good chance (about 90%) having this runoff in January, a good chance (76%) in February, and an in two out of three years he may be able to fill his

reservoirs in March. It all depends of how much risk is acceptable to continue emptying the reservoir as late as possible. Under the conditions of the areas under consideration, taking risk for one out of three years is common and it would not seem unwise to wait until March to start the conservative management of the reservoir water.

Table 1. Probability (%) of having certain amount of rain or more at or after the 1st of the month in Muwaqar*

Rain mm	Oct	Nov	Dec	Jan	Feb	March	April
7	100	100	100	100	93	83	35
10	100	100	100	100	98	76	26
13	100	100	98	89	76	67	22
15	93	93	89	76	61	50	17
20	83	83	74	63	48	37	7
30	46	46	46	35	26	20	2
40	22	22	22	15	11	7	2
50	11	11	11	7	7	2	2

* Calculation was based on rainfall record during the period of 1939-1992.

Analysis of Rainfall Events

a. Analysis of the number of rainfall events at the Muwaqar catchment shows that (Table 2) one rainfall event has a 100% chance of occurrence. Two events have a very good chance of occurrence (85%) while a 65% chance exists for having three events in one season that can fill the reservoirs at the UJRFM. If the reservoirs, at the time of runoff occurrence, were not fully empty, higher chance to fill the reservoirs exists. It would be reasonable to rely on three fillings in one year under conditions of the Muwaqar catchment. T his means that the operating capacity of the reservoir can be three times the physical or design capacity if properly managed.

b. When checking if there can be adequate time between runoff events to empty the reservoir, the analysis shows (Table 2) that a minimum of one week may be assured for emptying before next runoff. In 19 out of 23 years, the interval between three runoff events (>13 mm/day) was more than one week. In case of two events (of >13 mm/day), 7 out of 9 events have interval of more than one week. It can be concluded that generally a farmer has no problem emptying his reservoir before other runoff events. However, if the reservoir was half-empty due to narrow interval, it will only reduce the chance of maximizing storage. In the winter, the requirements for irrigation is not very high so one may want to store the water until late spring or summer. Under these circumstances, dumping (i.e. storing) the reservoir water in soil profile is highly recommended.

Table 2. Probability of having rain events of 13 mm/day or more and time between events at Muwaqar during 46 years.

No. of events Per year	Prob. of Occurrence per year %	Number of cases recorded over 46-year record			
		< 1 week	1-2 weeks	2-3 weeks	>3 weeks
1	100	-	-	-	-
2	85	2	0	1	6
3	65	4	4	3	11
4	41	2	4		3
5	37	10	3	3	12
6	20	6	4	4	1
7	15	3	2	1	6
8	11	8	1	3	2

Problems of Farm Reservoirs

Three major technical problems are associated with farm reservoirs. These are accumulation of sediments, evaporation, and seepage.

Accumulation of Sediments

Accumulation of sediments in the reservoir bottom reduces the capacity and the useful life of the storage facility. The rate of sediment accumulation depends on the surface conditions of the catchment, slope, rainfall characteristics, and the management of the reservoir water. Usually, steep lands with poor vegetative cover exposed to intense rainfall yield high rates of sediment accumulation. The longer the water stays in the reservoir (residence time) the higher the amounts that could settle on the bottom. The amount of sediments in the runoff water can be easily determined by sampling the flow at different times and flow rates. Annual depth of sediments expected to accumulate can then be determined when the total volume and retention time of the storage facility is known. After building the reservoir and under the conditions of temporary fill, previous sediments are measured directly by digging a profile in the bottom or by installing a permanent gauge at different points in the lake bottom.

Sediments was measured in the runoff water at the UJRFM reservoirs in the 1988/89 seasons and found to average bout 15 mm per meter of water depth stored in the reservoir. When measuring the accumulated sediments in the three reservoirs later, it was found that the accumulated sediment is much more than the 15-mm times the depth of water in the reservoir. This is because the reservoirs were filled several times every year and that usually flow occurs after the settlement of the water but before it's emptying. This means more sediment will accumulate without having more water unless the reservoir is emptied before next runoff. This supports the suggestion that farmer should utilize the water immediately after runoff. It was also found that, in two years, dams 1, 2 and 3 have accumulated an average of 52, 35 and 28 cm of sediments respectively. The higher sediments in reservoir 1 than either reservoir 2 or 3 are due to the fact that these reservoirs are built in series. The first dam acts as a settling basin for the second and the third dams.

In these small reservoirs, sediments can be removed to maintain its capacity and increase useful life. The economics of this choice depend on the cost of silt removal and the return of the secured water. The removal of sediments from the reservoirs at the UJRFM was found feasible. The operation was conducted 3 times over the period of 1986 to 1997. The average cost of removal varied between 0.5 and 1.0 JD per m^3. Knowing that the removal of one cubic meter allows storing over 30 cm^3 of water before it is filled again makes the operation worthwhile. This practice enabled the useful life of the reservoir to extend over the last 10 years while maintaining good reservoir capacity at all times.

Sediment accumulation can be reduced by controlling erosion at the catchment or by arresting sediments before intering the reservoir in settling basins or silt traps. Micro-catchment water harvesting or soil conservation measures also help in reducing runoff and hence improve the reservoir capacity and life. The reservoir bottom occupied by sediment is a fertile land and may be cultivated every spring after the end of the storage utilizing the residual soil moisture.

Evaporation Losses

Evaporation from reservoir surface can be a substantial loss if water stays long time during high evaporative demand. Conventional methods of controlling evaporation are presented in UNEP (1983) These methods include:

1. Minimizing reservoir surface area by increasing the depth relative to the area (Schneider, 1975);
2. Covering the water surface with various types of materials and films;
3. Provision of shading and windbreaks;
4. Concentrating remaining water after partial use in deeper parts of the reservoir to reduce the surface area, and, when possible; and
5. Avoid high evaporative demand periods.

Most of the materials used for covering the water surfaces are ineffective, costly or not practical. It may be useful under limited number of conditions but not the conditions of farm reservoirs in the dry areas of Jordan and similar areas dominated by hot windy conditions. Some improvement could be achieved in decreasing the surface area through planning or afterwards, but this is not always possible and moderate success under these conditions may be expected. The most effective way of controlling evaporation can be achieved through proper management of the reservoir water. The strategy of minimizing the time which water stays in the reservoir minimizes also evaporation. The other option is to use the water in the cool winter when the evaporative demand is minimum. Evaporation rate, which is low in winter (4 mm/day), rises drastically after the end of March. Adopting dynamic management of reservoir water and using it in supplemental irrigation saves substantial evaporation losses and ensures higher water use efficiency.

Seepage Losses

Seepage through reservoir bottom, although considered a loss at the farm level, contributes to ground water recharge. At the national or even the basin level, this is not a real loss, rather another mean of storing the water, which may be otherwise lost in evaporation. In fact, many of the small earth dams are built purposely to support groundwater recharge. However, understandably farmer's objective is to minimize seepage losses. Literature provides, in addition to proper selection of the site, several methods for reducing seepage. Most of them are based on sealing off the reservoir bottom using compaction or lining materials (Frasier and Myers 1983) and Hudson 1987.

Seepage from the UJRFM reservoirs is not serious. Losses from reservoir No.2 over the period from March19th to May 10th 1988 was found to be about 1.2 mm/day. After removing the sediments from about half of the reservoir bottom, seepage rate was increased immediately to 3.7 mm/day.

Seepage could be a major problem in some situations but for the arid areas of Jordan and in particular the Muwaqar catchment it may rather be desirable to enhance ground water recharge. This is particularly true because most of the runoff water is lost due to lack of proper storage and management. Again, the most effective way of controlling seepage is through minimizing the storage period.

Water Quality

All stored water in this type of reservoirs is surface runoff originates from rainstorms. The only pollutants expected are those existing on soil surface at the time of runoff. In the dry areas, there can be some salts in the surface layer of the soil but this would have been washed away with frequent runoff. The obtained water quality as a result is usually very good. The water quality of the three reservoirs of the UJRFM is no exception. The salinity of the water stored in dams 1 and 2 was compared to that of the rainwater in the seasons of 1987-1989. Runoff water has a salt content 4 times higher than that of rainwater falling within the same catchment. First runoff carried higher salt level than the following events. This is due to the fact that most of the salt on the surface is washed by the first runoff event. At the end of the season, salt was concentrated in the reservoir water due to evaporation. Small amount of livestock manure appears in the reservoir after the first flood. Although the amount is negligible at the moment, the potential pollution by these sources as well as possible human activities might increase unless proper measures were taken.

Environmental Issues

In the dry areas of Jordan, the positive impact of the uncontrolled runoff on environment is limited, since most of it is lost in evaporation. In the areas surrounding or served by small farm reservoirs, a new environment was created. The availability of water, improved agriculture and vegetative cover has created favorable conditions for active wild life and the germination of many plant species not recorded before the construction of dams. Large numbers of birds, hawks, wild rabbits and ducks started to be part of the ecosystem around the reservoir. Recharge of ground water improves water resources availability in other areas and hence environment. Soil was improved with cultivation and fertility improvement. Wind erosion is reduced with improved vegetation.

Generally, most of the effects on environment are positive. However some negative impact may occur in downstream areas deprived from runoff water as a result of storing it in the reservoirs. Encouraging maco-catchment water harvesting indirectly encourages soil-water erosion. Development around reservoirs attracts human activities with some abuse to the environment in a way or the other. Water bodies usually help the creation of vector habitats and increased incidence of malaria, schistosomiasis and other diseases (Carter et al., 1989). This could be a problem around permanent reservoirs with high temperature. Conditions favoring such incidence do not exist in these systems since water is used in the winter and little stays until summer. Overgrazing was reported in unprotected areas near the reservoirs.

Socio-Economic Factors

Analyzing the economics of farm reservoirs, like other water harvesting systems in the dry areas, is not a straightforward procedure. Generally, agricultural economists analyze the WH systems with conventional methods using direct benefits and costs. The results of such analysis do not often meet the high expectations placed on these projects. However, a major mistake is often made by ignoring the indirect benefits to the farmer, the community, the country as a whole, and to the environment. Successful water harvesting systems in the rural areas slow down migration to cities, which is very costly. It reduces erosion by wind and water, which is not easily measured, but helps the effort to fight desertification and to improve the environment. In these fragile environments the "cost of doing nothing" is very high and if accounted for in the economical analysis, the investment in these projects will be highly justified. Rightfully, many countries in the region had realized this fact and provided substantial subsidies to make these projects more attractive to the local communities. However, innovative methodology for the economical analysis of these systems under the fragile environments of the dry areas is still needed to meet the objectives of the national development and environmental protection.

The last but not least is the social aspect associated with these systems. Acceptance by the farmer is the key to any sustainable implementation. Examples from other areas show several unsuccessful projects designed and constructed on sound technical basis. When the farmer does not feel that he owns the system, he does not maintain it, and it collapses after the withdrawal of the provided incentives. Farmers need to be involved from the beginning and should contribute to the implementation to promote his senses of ownership. Subsidies and incentives need to be carefully organized to insure that the farmer is not cooperating only to get them.

Other social issues associated with the farm reservoir in the dry areas in general and that of Jordan in particular include water rights, land ownership, upstream-downstream effects, maintenance, and the role of women. Of most important are the first three. As of now there is no defined water rights legislation for runoff water in the Jordan badiah and most of the dry areas in the region. With water getting scarcer and people increasingly utilizing this water, conflicts will start to appear. Consequently, laws to regulate water rights will be needed. Land ownership is also not very clear as in the higher rainfall areas. Nevertheless, land fragmentation has recently started in some part of this area. Land ownership in this area is expected to influence strategies regarding the adoption of small size farm reservoirs. This influence stems from the following conditions:

a. Rapidly changing ownership size did not seem to be a problem in the past. Interest in such area is increasing due to resource scarcity and favorite prices in adjacent areas.
b. The location of the reservoir is governed by several factors. However, when the size of the farm is small water has to run from one farm to be stored in another. Legislation will be essential to regulate upstream-downstream relations to minimize conflicts.

A serious problem arises when water is utilized upstream of the catchment depriving downstream users of their share. At the moment, the runoff water is under-utilized and no problems are imminent. However, it will not be long before such conflicts appear. Particularly, when farmers use micro-catchment water harvesting systems upstream preventing runoff from reaching the wadies. Avoiding such a problem in the near future requires good planning. The solution should be based on optimizing water harvesting at the catchment level. A master plan of recommended techniques and alternatives to be implemented as development proceeds is vital. Solutions to these problems will attract farmers to adopt water harvesting in general and farm reservoirs in particular and should enhance the availability and use of rainwater for agricultural production in dry environments.

Conclusions

Small water harvesting reservoirs are a viable option in the dry areas. If properly planned, designed and implemented, they improve rainwater use efficiency, agricultural development, and environment. However, unless selection is based on maximizing water use efficiency, they might not be the best option. Making water available for agriculture may not necessarily mean good agriculture. Several problems both technical and socioeconomic need to be solved before WUE is maximized.

1. Higher water use efficiency is obtained if the water stored in farm reservoirs was utilized in winter conjunctively with rainwater than keeping it until summer. Extending the use of water to the summer reduces water use efficiency due to higher evaporation seepage losses.

2. Storage capacity can be multiplied if a Maximum Capacity Option was adopted. That is encouraging pumping water to store in the soil profile to allow more storage capacity in the reservoir. Large areas can be cultivated with reasonable risk.
3. Sediment removal is worthwhile doing to extend the reservoir life and capacity.
4. The government is encouraged to subsidize this type of work, develop water rights legislation, solve land ownership problems and act positively to implement comprehensive development plans for the area.
5. Socio-economic issues related to upstream-down stream rights may complicate the management and the adoption of small farm reservoir. Community-based management, farmer participation in planning and cost sharing, or the establishment of a cooperative can be among alternatives recommended to manage these reservoirs and to overcome the problem of small holdings.
6. Large-scale adoption reduces the cost of the spillway.

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Issues and Options for Integrated Water and Land Management in the Indus Basin

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Pakistan and its Basins

Pakistan is located between latitude 24°N to 37°N and longitude 61°E and 75°E. Its north boundary is constituted by Trans-Himalayan ranges stretched into China, India and Kashmir. These snow-covered peaks are the major source of river flows in summer. I ndia is in the east and northeast, sharing the mountainous river catchments. The North-western boarder is shared with Afghanistan across the Karakurum and Hindukush ranges; which allow western winds to bring sparse but valuable rains in winter. The western border with Iran divides vast desert following the Waziristan hills, driest zone in general but the lower part having access to monsoon. Arabian sea is in its south providing drainage outlet to the residual flows of streams and groundwater effluent.

The total area of Pakistan is 796,100 km^2 (80.396 mha). The total cultivable area is estimated to 37% or 29.9 million ha, 55% (16.5 mha) of that is cultivated (in 1999). The 80% of the total cultivated area or 14.8 million ha are irrigated. According to the national census of 1998, total population of Pakistan is 130.57 million, 67.5% residing in the rural areas.

The physical relief of Pakistan is shown in Figure 1. From mountains in the north, Indus river and tributaries stretch to the south. The green belt along the rivers and three dry areas can be observed. The vast area in south-west has non-uniform landscape, hilly regions, desert and small water streams. Another desert area lies along the south-east boundary with India. A dry area can be observed in north-west, surrounded by the green belt; the Thal desert which lies between Indus and Jhelum rivers.

Hydrologically, Pakistan has two small and one big basins.

<u>**Kharan Desert Basin**</u> in the west covers 46,400 sq. miles of Baluchistan province and about 15% of the country. The basin includes dry hills of Quetta, Khgaran desert, dry lakes and a few small streams. Rainfall is the main source of water, which is generally very little from the western winds in winter and from the monsoon tail in summer. Basin's population is thin and depends upon grazing and wood.

Makran Coastal Basin is situates towards southwest near lower Indus delta. Its area is 47,300 sq miles. The basin has small flashy streams and erratic rain patter. Some of the streams have base flow. The basin is more populated than Kharan basin. The main profession is fishery in the coastal area, there are delta forests, the rice, maize and vegetable cultivation also exist. The water resources of the basin are underdeveloped.

Indus Basin covers more than 566,000 km^2 (216,700 sq. miles) or 71% of Pakistan located in all four provinces. The Indus basin comprises eight river basins, now physically inter-connected through a network of river reaches, inter-river links and huge conveyance canals. The Indus and its tributaries, Jhelum, Chenab, Kabul, Swat, Ravi, Sutlej, Beas and many other streams originate from Himalayas, Karakoram and Hindukush regions and descend south towards the Arabian Sea. The river Sindh (Indus) itself is augmented by numerous streams of various sizes when passed through the Northern region.

The climate, hydrology and physiography of the basin changes from the north to the south. The North is much less arid with 500-700 mm rain and 900-1100 mm evapotranspiration than the south with less than 200 mm rain and more than 1500 annual evapotranspiration (Kaleem 2001). The soil changes from course gravel to loam and sand. The basin accommodates 80% of country's population and almost all of its irrigated agriculture.

Objectives of this Paper

By making a reference to the natural eco-systems, planning and development approach adopted in Indus Basin; this paper presents availability, utilization and distribution trends of water and land resources and highlights the potential and constraints of the system, which must be considered for the integrated planning of the natural resources. This serves two objectives. Firstly, the paper presents the gross impact of existing management practices. Secondly, the paper identifies problems, which must be considered for integrated planning.

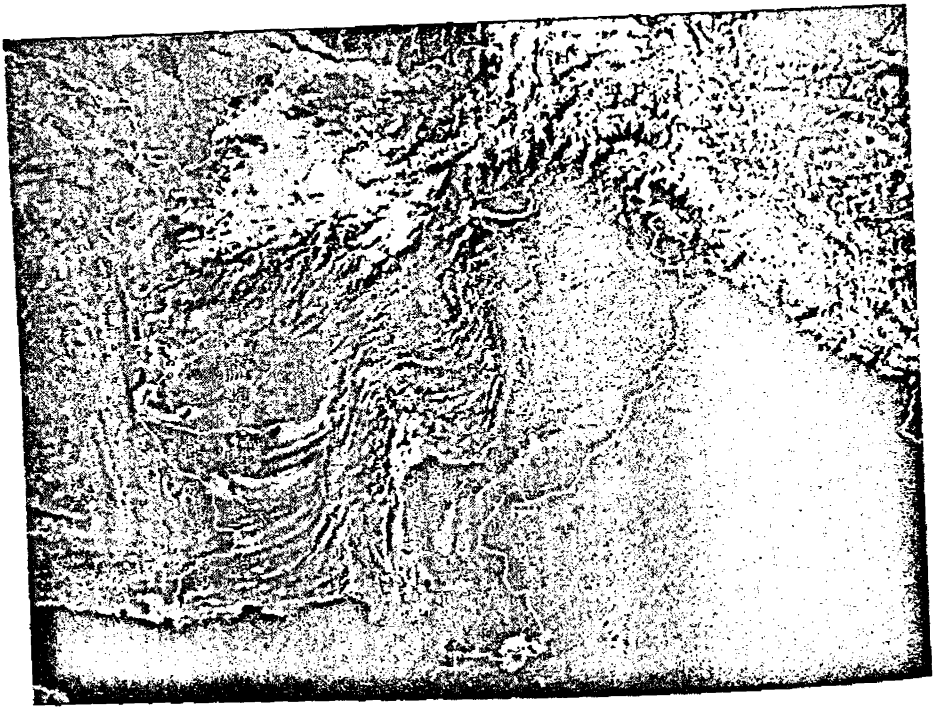

Figure 1. Relief map of Pakistan

Traditional Agriculture and Eco-Systems of Indus

The fertile land of the basin has been experiencing a variety of agriculture since centuries. Its big arid and semi-arid plans, harsh climate and five rivers accumulating on numerous streams provide a rare combination for agriculture and irrigation both. Long before the "era of irrigation development" starting from the mid-nineteenth century, most of the Upper Indus (Punjab and NWFP provinces) soils were considered suitable for agriculture, and the farming communities, tribes and villages were liable to pay agriculture tax (Ain' Akbri 1685). In the lower basin (Sindh and Baluchistan), wide spread low floods from Indus and monsoon were able to provide moisture for summer irrigation, fill wide scattered village ponds and wells and recharge the groundwater aquifer.

Hughes (1928) appraised the soil-nature-man ecosystem of Indus plains. "The inland position of the Province (Punjab), combined with sandy nature of its soils give rise to great extremes of temperature.—At the edge of mountain area and river beds grasses grow to a great height, and the smaller drought resisting trees produced the dense jungle, which is the congeniual haunt of big animals. Heavy monsoon rainfall (13 inches), which comes just when it is most required, much smaller winter rainfall, which comes just when it is most wanted. But, the dry plans in central Punjab can never have retained sufficient moisture for forest growth. The river rises and flows to the several miles on both sides, leaving the fertile loam and sand. Beyond this flooded area, the land is low and percolation provide moist to dug and use wells. The cattle are used to operate these wells 25 to 70 feet deep. The uplands between the rivers were only fit for grazing (supplied irrigation canals later on). The abundant grass and rain fed fodder afford large herds of cattle, whose excellent milk yielded a large and valuable supply of butter. Towards the desert, herds of camels fed on the leaves of deep-rooted trees. Here and there is a deep well that provides water for cattle and man."

The heavy floods were never easy in Punjab and Sindh plains of Indus, because of flat slope, water spreads to the large areas, which keeps agriculture communities wandering around. Aristobulus, Alexander's companion saw the remain of over a thousand town and villages in a region left desert by shifting of Indus towards east (Cambridge 403). Two archeological sites Mohanjudaroo (lower Indus) and Harrapa (upper Indus) give evidence of a developed civilization between 2000- 3000 BC. In both cities, techniques for crop production, grains saving and urban water supply systems were available.

The man-soil relationship, untreated to the level of raw and intuitive in human interaction, survived the hardship of nature, big migrations of population, wars, invasions and the changing relationship of society and state. The Indus people learn not only to select and grow valuable crops, many agri-products were processed, used or exported. One of Alexander's companion writes in 300 BC, "The reeds that make honey without the agency of bees, cotton plant yielding vegetable wool surpassing in beauty and quality the wool of sheep (Cambridge 135—396)". The trade of spices, blue (color) ivory, refined animal butter, silk and leather to west Asia and Central Europe was there from the sea route (Karachi) in 5th to 7th century. A rich agriculture has been reported in 15th and 16th century. The writings of that period talks about cotton, wheat, barley, corn, millet, grams, beans, lintels sesames, sugarcane, rice, fodder, silk and spices, fruit, color bushes, grapes, watermelon, and pomegranates (brought from Central Asia). The export of rice, cotton, silk, spices, organic and animal butter is mentioned in by Ian-e-Akbri (1656). Between 13th and 17th century, inundation and flood canals were developed by the communities of the basin, local rulers and Mughal kings (Irfan Habib, Moorland, Thomson-1921).

Historical Management Approaches for Agriculture Resources

The traditional systems of the basin did not have a single management model, the role of state was minimum as a direct manager or facilitator, but supreme as an authority which is a beneficiary and may act from time to time. The cultivation systems were locally managed by kinship or tribe based groups, with no very clear concept of ownership and with some flexibility of sowing as much land as possible. A common function of state/states was to get a share of agriculture produce and facilitate trade. Mostly, an administrator or "de-facto superior owner" exists between the state and agricultural communities. The role of this authority, nominated by the state, was to ensure the continuity of agriculture production and to collect revenue.

Development Priorities of Modern Irrigation Infra-structure

1. The areas with higher potential of agriculture, having enough state lands and favorable for settlement were given a priority for irrigation development (Table 1). The development chronology was somewhat like this:
    a. Already existing inundation canals with improper functioning were improved, some of them changed to the weir control system (Halsi, Westren Jamna);
    b. The areas with population and political stress were provided with new irrigation system and canal colonies (Lower/Upper Chenab Canal; areas fed by Chenab, Jhelum and Ravi rivers, Central & Northern Punjab); and
    c. The areas with high natural feasibility for irrigation but low population density were provided with canal system, these projects were considered "highly

beneficial" due to sale of crown-waste land (Sutlej Valley Project, Thal)

2. The areas with bad groundwater quality, low rainfall and difficult natural drainage were developed at the later stage.
3. The higher volumes of river water were required for agriculture in highly arid areas with low quality groundwater, areas have drain ability problem due to flat natural surface slope. While the water left in river network was limited during major part of the year. The canal supply was provided to bigger proportions of these areas only in summer but in higher volumes.

Table 1. Chronology of irrigation development and quality of resources

Period	Area with good Groundwater	Rainfall	Perennial Area	River Irrigation Supply
1859 -1920	95%	300 to 600 mm	> 80%	600 mm
1920 - 1930	70%	200 – 350 mm	50%	600- 800
1930 -1960	45%	150 to 300 mm	75%	600-2200
1960 - 1980	33%	< 200 mm	30%	700-1800

4. A task undertaken by the planners was to make alluvial channel profitable and accessible for irrigation to the maximum areas and population, scattered in the range of hundreds of kilometers from the river regimes. Hence, very big earthen channels were constructed for proportionate distribution of water. Delivery was based on water depth and gravity flow with minimum control structures. The network was logically simple but huge and hierarchical having three stages of the physical system and thousands of farmer's channels on each main canal.
5. No drainage effluent was expected with thinly spread water. An assumption could only work, if all diverted flows are utilized or returned back to already existing conveyance network. In the earlier system, water allowance was readjusted if waterlogging is witnessed.
6. The rural infrastructure did not have a concept of domestic water supply network, neither of industrial water requirements when the system was designed. Based on the prevailing practices, water acquisition and management was left to the individual households.

Physical System of the Indus Basin

A physically interconnected conveyance and irrigation system finally took a shape after the Indus Basin Treaty of 1960. The intervention provided by three reservoirs and seven inter-river link canals made a basic difference by introducing a flexibility in a rigid run of the river system. The Figure 2 shows a schematic of river-canal system of the country, all nodes on the rivers are indicated. The river water distribution network covers predominant fraction of fresh water supply for all purposes because of low rainfall. A brief summary of land and water availability and utilization is given in Table 2.

Table 2. Gross resource characteristics of Pakistan

Land Availability and Utilisation		*Water Availability and Utilisation for Irrigation*	
Gross Area of Pakistan	80.5 mha	Average River Inflow	172 bcm
Population (1998)	130.5 million	Diverted from river nodes	128 bcm
Reported Area			
Mountains and foot hills	41.5 ha	Other than irrigation allocations	3%
Indus River Plains	39 mha	Rain below river catchment	75mm–460mm
Forest	3%	Rainfall volume (avg. year 1994)	83 bcm
Cropped land	22.4 mha	Rain in canal Irrigated Zones	24 bcm
Total Irrigated Land	18.2 mha	Daily Reference Evaporation	3 mm – 6 mm
Rain-fed Area	2.2 mha	Annual Reference Etn	700-2300 mm
Land with useable groundwater	65%	Area with Groundwater Pumpage	75%
Good Quality irrigated Land	73.6%	Recycled water	40-50 bcm
Waterlogged area (1996)	30%	Gross Saline Area (1980)	30%

The notable points here are: 75% of river inflow is diverted for the uses. Thirty percent (30%) of the total and 60% of the reported area is cropped, while 85% of the cropped area is irrigated.

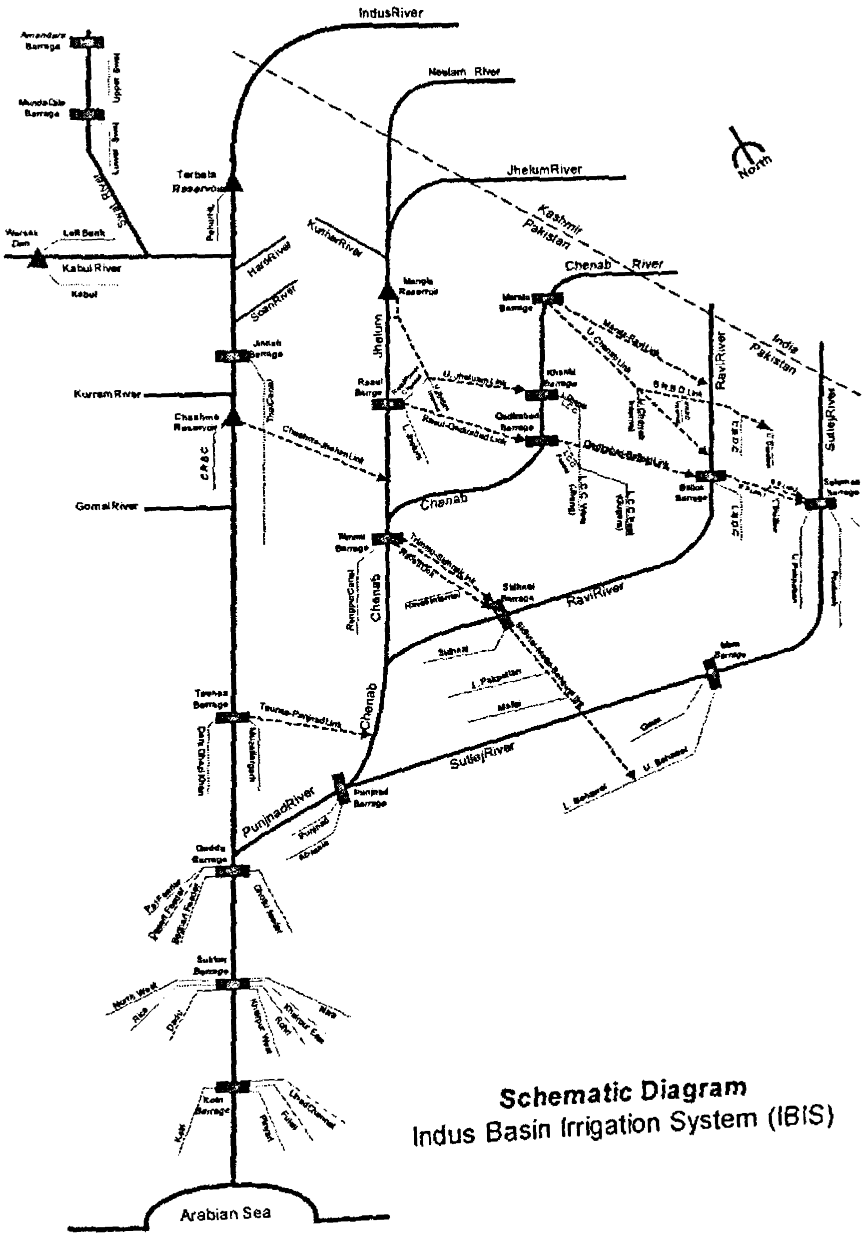

Figure 2. Indus basin irrigation system – a schematic diagram

Challenges and Constraints

The population is a key stress factor for the natural resources and infrastructure. The growth rate of agriculture production is not promising, 5-7% during the last four decades of twentieth century. A major challenge for the public sector is to maintain per capita supply of food, clean drinking water and other facilities. The population of the country has increased at a rate of about 3.5 % from 1951 to 1981 and at 2.6% from 1981 to 1998 (Figure 3). It sets the minimum growth target for the basic necessities.

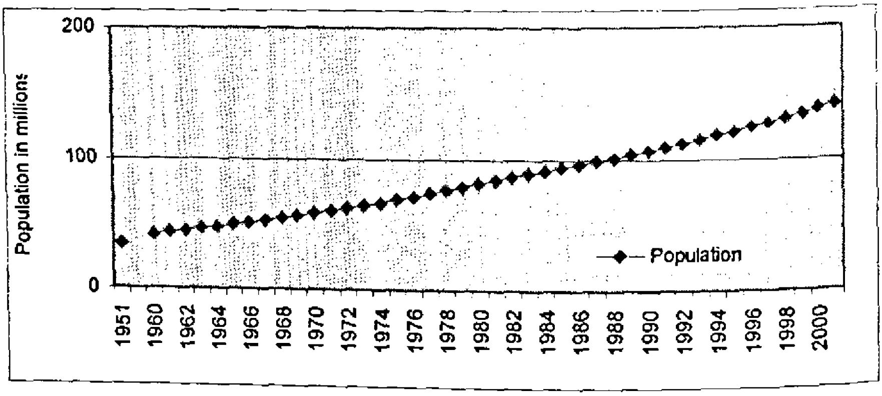

Figure 3. Annual population of Pakistan based on the census of 1951, 1961, 1981 and 1998

Depletion of Resources

The depletion of resources in Indus basin in a quantitative sense is there due to population increase, higher uses and new demands at the sectoral level. There is also a qualitative depletion due to addition of salts into water and land, waterlogging, increased use of marginal resources and negative conservation balance of natural resources. The temporal trends of water and land use and their spatial character show different type of challenges are faced under different conditions.

Table 3. Population, cropped area, river inflows and irrigation diversions

Periods	Population (millions)	Cropped Area (MHa)	Total River Inflow (bcm)	Irrigation Diversions (bcm)	Outflow to sea (bcm)	Ground-water Pumpage (bcm)
1951	33.82		233	83.0		4.00
1951-65	51.00	15.54	198	104.9	97.1	12.5
1965-75	71.60	18.00	185	117.9	53.5	33.5
1975-85	96.54	19.92	179	125.6	44.3	48
1985-95	121.73	22.14	198	131.7	58.5	59
1995-2000	137.45	22.9	194	129.0	27.5	64
2001	140.98	22.5	124	104	2.5	66

Towards a Water Scarce Country

Pakistan has moved rather quickly from a water-abundant to a water-scarce country. The per capita availability of total gross inflow or fresh water has decreased from 8200 m^3 in 1951 to 1000 m^3 in 2001, as shown in Figure 4. The gross inflow is contributed by total river inflow and rain entering into the basin. Increase in population is the main cause of per capita consistent decrease in the gross water availability. The Figure 4 shows two periods of abnormal decrease: a big downward slump during 1951 to 1975 is contributed by a loss of about 30 billion cubic meters (bcm) water of eastern rivers compromised to India under the Indus Waters treaty in 1960.

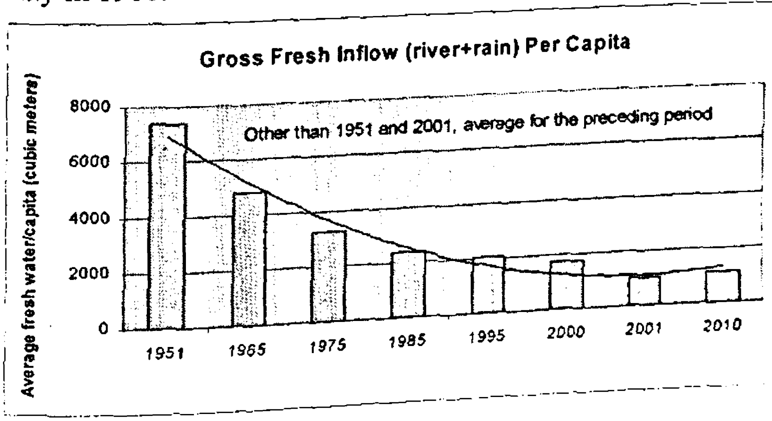

Figure 4. Per capita gross inflow into the Indus Basin

Another abnormal drop was faced in 2001, when the gross inflow decreased by 35% as compared to the average of previous five years. The vulnerability of this stress was high due to a critical gap in demand and supply. A famine like situation outside the irrigated areas forced special food and water supply, still the tribes have to leave the area with a loss of animals and property. The Figure 5 shows some of the areas were officially declared as affected by draught in 2000. Severely arid areas are those where dry spell continues till the first quarter of 2001 (2 years). Rainfall is the only source of water in these areas.

The impact of decreased river flows has not been less damaging in irrigated areas. The Sindh province, which has bad groundwater reservoir, reported 25% decrease in cropped area and about 10% in the yield of major crops. It put Water Apportionment Accord of 1991 among the provinces, at risk. The provincial representatives in Indus River Systems Authority (IRSA) could not reach to a common interpretation of the guidelines set for the water sharing in volumes and over the time. The pressure from farming communities in each province during the stress periods made it more difficult for the administration to reach an agreement. The problem was solved administratively by the intervention of the central Government. A disagreement continued about the sharing of shortages

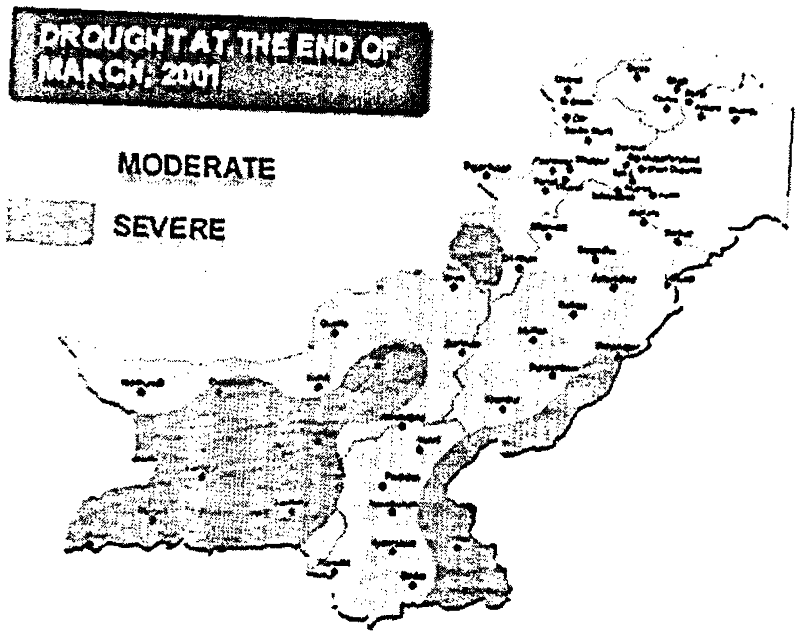

Figure 5. Draught areas declared by the MET office

Per Capita River Diversions and Groundwater Utilization

Per capita annual diversions of fresh water have decreased to less than the half (2500 to 950 cubic meters/person) during 1961 to 2001 (please see Figure 6). While the net diversions have increased from 104 bcm to 135 bcm (about 25%). Population increased from 42 million to 140 million during the same period. The depletion factor due to huge increase in population is pre-dominant and alarming.

The groundwater provided some relief during the period, but reached to the exhaustion level as well. The annual pumpage of groundwater developed from 4 bcm to 66 bcm during 1960-2001. Its per capita availability swiftly increased during the first fifteen years. The level was maintained for a decade with 3% annual increase in pumpage while a decreasing per capita availability could be seen in the recent years.

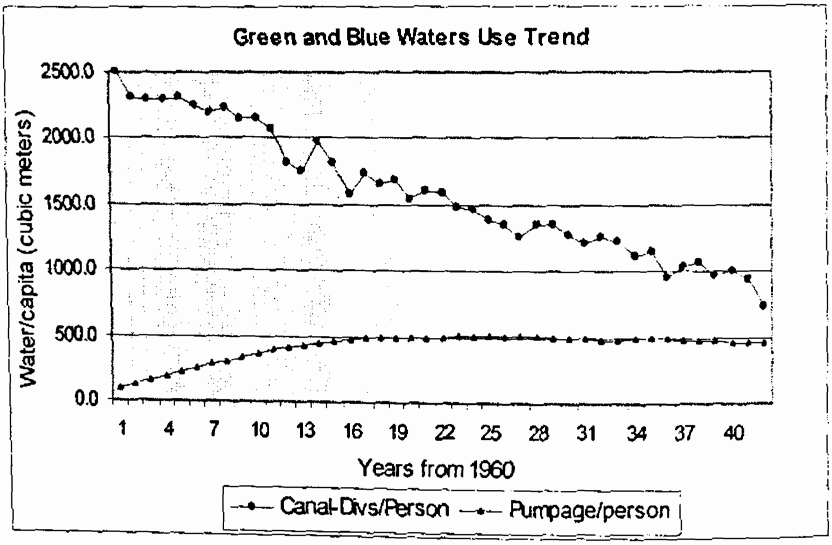

Figure 6. Canal and Groundwater diversions over 40 years

This leads to another alarming situation where increasingly higher percentage of moderate quality groundwater would be available for different uses, while the consumption rate of fresh and groundwater would decrease.

Depletion of Quality (Salinity and Waterlogging)

The land salinity in Indus Basin is mainly caused by high water table in the saline groundwater zone (WSIP 90, NDP 94). The salinity map of 1976 and groundwater table of 1998 shows that most of the areas, which were saline in 1976, are water logged in 1998, having a water table at three meters (root zone for most of the crops) after monsoon season. In major waterlogged areas rainfall is about 200 mm and evapotranspiration 2000 mm, hence recharge comes from the irrigation system and/or from the sub-soil inflow. The canal supplies to these areas are higher than the other systems (Table 1) and are partly seasonal. Substantial seepage and percolation losses occur during conveyance and field application, estimated to 50% - 70% of the canal diversions (LIP 65, RAP 67). Unfortunately, many drainage projects implemented in these areas are controlling the waterlogging. The following characteristics are important for drainage planning:

a. Surface slope is flat and provide small hydraulic gradient;
b. Groundwater is mostly not useable and very small amount is pumped;
c. Fresh surface water added to the ground-sink lost for any other use; and
d. High water table is a reason for the farmers to grow rice.

Depletion of Groundwater Reservoir

The water table is deeper than 600 cm in some irrigated areas, this is the zone with good or moderate quality groundwater. The average change of groundwater table in forty-three canals command area over six to nine years is shown in Figure 7. For eight canal commands, gross depletion is 50-150 centimeters, while ten areas have net depletion of 10-40 cm. Another eight command areas have water table rise of 50cm to 150 cm. In 50% commands, a reasonable balance of water supply and use exists. Some of the "balanced water use" areas are, however, waterlogged and not improved during the period.

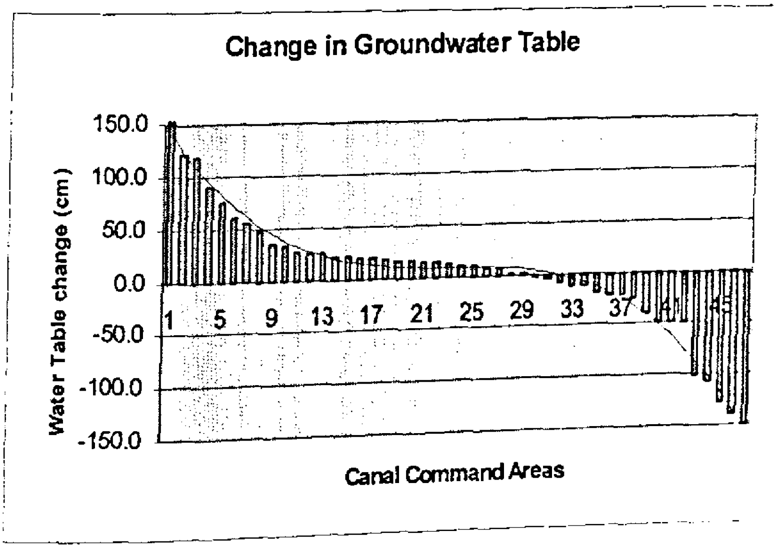

Figure 7. Change in groundwater table, command area average

The groundwater pumpage and water table depletion confirm the conclusion of some recent studies that groundwater use in the sweet zone has achieved potential level of exploitation (NESPAK 94, WAPDA, NDP Consultants, vision) and current extraction is higher than recharge. The mining of aquifer in sweet-zone would increase, because it is the only source to compensate the surface supply and fill in the gap between demand and supply.

Sustainability of Agro-economy

Water and Land Constraints

The expansion of agriculture by increasing cropped areas and diverting as much water to the canals system as possible have been two important planning tools for the enhancement of agriculture production in the basin. An extensive use of resources was proposed at the design stage by low water allowance, small cropping intensities and non-perennial supplies. The stress irrigation was planned with less than 600 mm annual supply at the head of farm channels (watercourse) to serve the maximum areas (systems designed before 1950). In these delivery systems, capacity of infrastructure and inflow hydrograph of the rivers are composite constraints, capacity not allowing peak summer supplies to be diverted, while flows remain much lower than the delivery potential for eight months.

The net efficiency of water use is high in the sweet water zone as all water entered into the zone is utilized. An increase in gross water availability and irrigated command area is possible only by extending infrastructure and diverting more water. The improvement of water use efficiency in saline zone is theoretically possible by saving water losses from irrigation infrastructure and field application. Different options and combinations are available to save the water from the supply and/or application system.

The extension of cropped areas by increasing cropping intensities has little potential left. The intensities in sweet zone have already reached 140%, groundwater is heavily pumped and reservoirs are depleting. The waterlogged areas of the saline zone as well as water short areas have relatively lower cropping intensities and lower per hectare gross production (Table 3). Further increase in cropping intensities would need higher efficiency of water use at the farm-gate, less water consumption crops and accepting higher water stress.

The increase of cropping intensities in rain-fed areas is even less likely due to high aridity and scarce groundwater resources.

Table 4. The spatial characteristics of irrigated areas of the basin (1995)

	Water Table cm	% area good ground water	Cropping Intensity	GVP/(ha-CCA) US$	GVP/m³ Irri. Supply US cents	Avg. Canal Allowance mm
Punjab I	474	92	106	183	2.78	543
Punjab II	406	78	133	282	3.32	889
Sindh I	241	55	66	144	1.52	1231
Sindh II	238	8	64	111	1.13	1182

Potentials of Irrigated Agriculture

The development patterns of cropped area and grain production are shown in Figure 8 and their per capita values in Figure 9. The grain production pattern gives good news, per capita kilograms increased at a greater rate than the population while cropped area per capita decreased (Figure 9). There was a sharp increase in grain production during 1966-71.

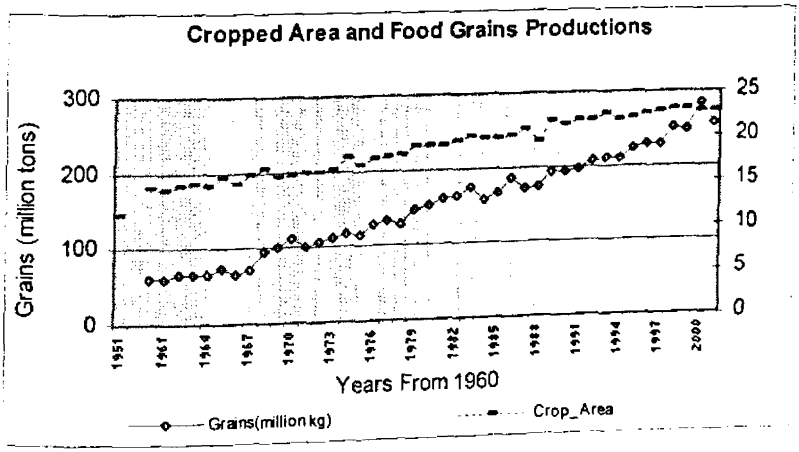

Figure 8. Cropped area and food grains productions

The new irrigation systems and reservoirs started functioning during this period. Production increased due to use of fertilizers and high yield seeds. After that it continued varying in a small range (per capita production) with an overall increase trend and periods of stagnation. An 18% increase in 2000 was breakthrough to make Pakistan self-sufficient in food-grains and a wheat exporter. Due to the draught, production in 2001 went down to the level of 1996, but was compensated by the excess wheat produced in the previous year.

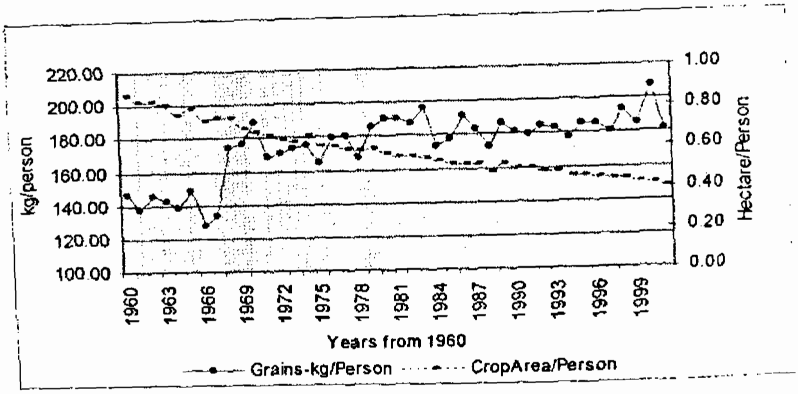

Figure 9. Per capita cropped area and grain production (kg)

However, the yield potential for the major crops is still not achieved and the average yield at the national level is low (Table 5).

Table 5. Average national yield and prices 1999-2000

Crop	Average Yield Kg/ha	Average support Price (Rs/40 kg)	Potential Yield Kg/ha (WAPDA)
Wheat	2100	300	3000
Rice (Basmati / Irri-6)	2805	185-425	4000
Cotton	1580	1800	2800
Sugarcane	50279	36	7000

In view of existing constraints water availability and the degradation of land quality, enhancement of crop yield is more feasible than the extension of cropped area. The crop diversification is another factor, which could help in improving gross economic output of the land and water. It can also help improving the sustainability of agriculture and minimizing the seasonal risk level.

The Livelihood Issues

The country has achieved food security and there is a potential to produce more. However, the livelihood of communities and households involved in agriculture is linked with the economic returns and access to the basic resources at their level. A detailed analysis of different livelihood aspects is outside the scope of this paper. The general character of distribution and production patterns is briefly presented to highlight the issue.

The land settlement policies in the basin resulted in unequal distribution and a majority of medium size land holdings. These continued dividing into smaller pieces with each generation due to big family sizes, Islamic inheritance law (which ensure division of inheritance among all descendants) and non-availability of other employment opportunities. The land holding survey of 1990 showed that 82% farming families had land less than 5 ha and 47% less than 2 ha (please see Table 6). Five hectare is an economical agriculture unit declared by the Government of Pakistan.

The level of livelihood risk faced by these small farms could be perceived by production pattern at the farm level. A socio-economic survey of 550 farms of different sizes in a command area of 67,000 ha gives the range of output distribution from zero to US$2,700 per hectare, as shown in Figure 10. The average returns, are low due to higher density of low producing farms.

The area has extensive use of groundwater, low rainfall, and cotton/rice- wheat cropping patterns (Molden 2000). These production and farm size distribution patterns are sufficient to indicate that the majority of farms are surviving on subsistence agriculture. It also emphasizes the role of farm-level interventions to increase productivity and farm management practices.

Table 6. Farm size distribution in 1990

Size of Farm(ha)	Percent Farms in the range	Percent Area in the range
0.5	13	1
0.5-2.0	34	11
2-5	34	27
5-20	17	38
>20	2	24

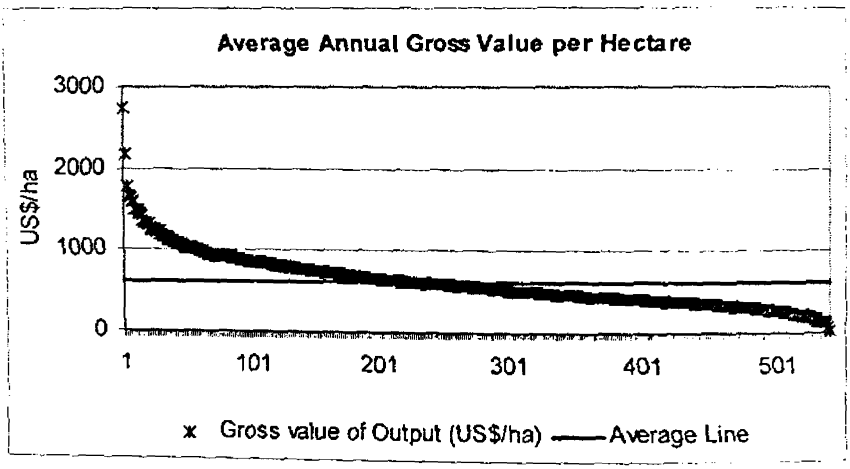

Figure 10. Farm level distribution of Gross Output

Urbanization and Industrial Development

A good account of existing urban and industrial uses of water is not available. Some recent estimations show rather higher diversions to big cities and high sewage rate (80%). The data presented by the "Interim Report of Ministry of Environment, Local Government and Rural Development (1999)" is summarized in Table 7 According to official estimation, 80% of the urban and 11% of the rural population is benefiting from piped water supply. Based on the information provided in Table 7, total domestic water use was 5 bcm in 1998. The value may be over-estimated for domestic uses, but shows that other than agriculture requirements are sizeable and needs to be accounted for. "It is estimated that the domestic and industrial water uses will increase from 3% to the 15% of available water resources (FFA, 2000)".

Less information is available about industrial uses, which are fully acquired and managed by the industries, mostly using groundwater but a small percentage has access to the surface supplies. It can be concluded here that it is the time to account for and consider in planning the urban, domestic and industrial water uses.

Table 7. Domestic-use water diversions

City	Water Supply (gallons per capita per day)	Population millions
Islamabad, Lahore	80	5.60
Karachi, Peshawar	60	10.26
Faisalabad, Hyderabad	50	4.86
Quetta	40	1.47
Other small cities	40	20.40
Rural Population	10	88.50

Integrated Management Scenario

A basic change in the mindset of policy makers and managers is required for a shift:

- from exclusive to inclusive planning,
- from project to sector and region oriented development,
- from single to many stakeholders involvement,
- from intensive to regenerative use, and
- from segregated to comprehensive management.

To address the depleting water resources, planning should accept a water scarce scenario for Indus Basin and base on a realistic account of availability and demand priorities while developing and allocating water resources. The regional and household food securities, the quantitative and qualitative depletion of groundwater and the future livelihood water requirements must be considered at this level.

The land and water are closely linked in the ownership and utilization, for 97% of the developed river resources. The water management approaches strongly influence the quality and productivity of land. A combined potential of both should be considered in the context of emerging other demands.

A more balanced use of water would need interventions like improvement in distribution, change in cropping patterns, water transfer over the seasons, reallocation of water and water saving from the agriculture. More than one measures are available for water saving in agriculture, technical and managerial both; like drainage, canal lining, water sensitive irrigation techniques and prioritized agriculture, reducing excess by better demand-supply and change of cropping patterns.

Sustaining agriculture in Indus Basin requires increasingly conserved and productive use of water and land potential. Still vertical potential of land exists in the enhancement of crop yield and per hectare productivity.

The existing agriculture economy is not strong enough to ensure farm level livelihood security to the concerned majority. Highly subsistence agriculture by an overwhelming majority of the farms could not ensure optimal output either. The farm-level interventions are important to be studied.

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Integrated Watershed Management for Minimizing Land Degradation and Sustaining Productivity in Asia

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Introduction

Land is the most valuable natural resource and fundamental to the life of mankind as it is the primary basis for production of food, fiber and many other essential goods needed to meet human and animal needs. It is a renewable resource so long as it is used according to its potential. Continued unplanned and unscientific exploitation leads to land degradation and to a non-renewable state. Although land degradation occurs all over the world, the problem is particularly serious where local food production cannot adequately provide living/survival to the people. The low agricultural yields and high population pressures have forced millions of small farmers to clear forests and cultivate fragile marginal lands, causing soil erosion and deepening rural poverty.

In general, land degradation implies temporary and permanent regression from a higher to lower status of productivity through deterioration of physical, chemical and biological aspects. The physical processes, which contribute to land degradation, are mainly water and wind erosion, compaction, crusting and waterlogging. The chemical processes include salinisation, alkalization, acidification, pollution and nutrient depletion. The biological processes on the other hand are related to the reduction of organic matter content in the soil, denudation of vegetation and impairment of activities of micro-organisms and fauna.

Of all the human-induced land degradation problems, the permanent loss of soil productivity due to erosion is the worst on a global scale. Degradation of vegetation, salinization, loss of soil organic matter and fertility, crusting and compaction usually are reversible. Accelerated erosion however occurs nearly everywhere where agriculture is practiced, and is irreversible. The major problem with the loss of nutrient rich fine topsoil is that it results in reduced productivity, which also results in silting of water bodies and streams (Black, 1968). It also induces erosion-triggered release of soil carbon (C) from particulate organic material, which is a cause of global warming. All these factors worsen the poverty situation; increase frequency of natural disasters such as floods and landslides, the concomitant loss of life, property and loss of biodiversity.

More than 50% of the irrigated lands in the world are affected by waterlogging and salinisation and are located in the Asia region. It has been estimated that about 75 million hectares of soil has deteriorated chemically in the region during the last 45 years. In South East Asia, Indonesia has 2.2 million hectares of severely affected soils. Land degradation in Asia is clearly shown in the Figure 1. Asia probably has suffered more from human-induced soil erosion than any other continent.

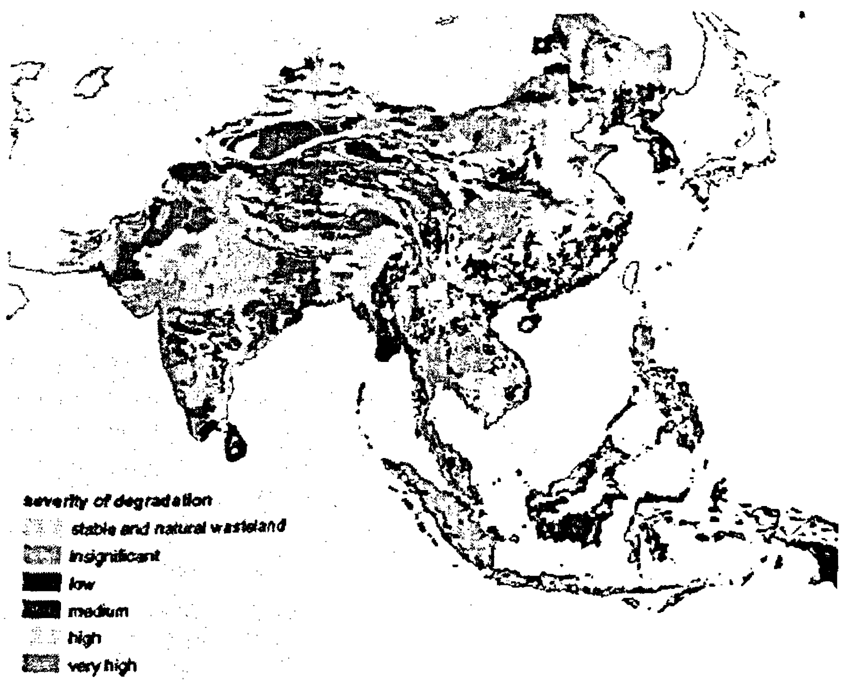

Figure 1. Extent of land degradation in Asia

Agricultural Activities and Land Degradation

Unsustainable agricultural practices account to 25% of the degraded soils in the Asia region. Common agricultural practices, such as insufficient use of fertilizers and shortening of fallow periods in shifting cultivation can lead to loss of nutrients. Too much fertilizer can lead to soil acidification. By saturating soil surfaces that are subsequently baked by sun, irrigation tends to deposit salts and other minerals where they interfere with root growth. Vast tracts of land that are left after shifting cultivation are exposed to the natural forces of erosion, thereby resulting in land degradation in the hills; heavy siltation and floods in the plains.

Cultivating virgin soils or altering a system of agriculture brings about changes both in the rate of addition of organic matter and the rate of decomposition resulting in decrease in soil organic matter (SOM) and more rapidly so under tropical conditions (Jenkinson and Ayanaba 1977). Comparison of cultivated land with native or uncultivated sites from many locations around the world showed that concentration of organic C decreased by 13–60% in the surface horizon of cultivated soils depending upon the soil type, management and duration of cultivation (Juma and McGill, 1986). Jenny and Raychaudhari (1960) studied 522 soils in India and calculated cultivation indices "CX and NX" (organic matter in cultivated soil divided by that of virgin soil) reflecting the percentage loss of SOM as a result of cultivation. They found values for CX ranging from near 100 for resilient paddy soils down to around 30 for most of the fragile environments. During a 30-40 year cultivation period, they found NX value from 73 per cent down to 40 per cent, regardless of the initial N content of the soil. At the research farm of ICRISAT cultivated field was compared with natural re-vegetation area to understand the soil degradation due to cultivation, the natural re-vegetation fields recorded 1.87 times more microbial biomass carbon (590 vs 315 mg C kg^{-1} soil), 2.42 times more microbial biomass nitrogen (13.8 vs 5.7 mg N kg^{-1} soil), more nutrient supplying capacity and more earthworm biomass (76 vs 2 g m^{-2}). The decreased biological activity in Alfisols was due to agricultural activities in the cultivated field and this clearly demonstrates the biological degradation occurring in cultivated fields over the natural revegetation fields (Table 1).

Table 1. Soil quality parameters in cultivated and natural revegetation fields at ICRISAT.

	Land with natural revegetation	Cultivated land
Earthworm Biomass (g m^{-2})	76.0	2.0
Biomass C (mg C kg^{-1} soil)	590	315
Soil Respiration (mg C kg^{-1} soil 10 $days^{-1}$)	180	160
Biomass N (mg N kg^{-1} soil)	13.8	5.7

In Thailand increasing population is straining the natural resources such as land and water and this had resulted in encroachment of forest area for agriculture. The runoff here is loaded with sediments which impoverish the soil and also cause reduction in the storage capacity of the water bodies. The key constraints are remoteness and inaccessibility, low biological productivity, degraded soil, pests and diseases. The sloping land ecosystems have much lower carrying capacity. In the sloping lands of Thanh Ha watershed, Vietnam, crop productivities of the fields located on different positions on a toposequnece were analyzed. Maize, groundnut, mungbean and soybean were grown on all the three toposequences in 1999 and 2000. The productivities of the crops in the middle and lower parts of the toposequences were higher than that of the fields located at top of the toposequence in all the four crops studied (please see Table 2). In Tad Fa watershed, North Eastern Thailand, maize was grown on a toposequence with steep slope (> 15%), moderate slope (5–15%), and mild slope (<5%). Maize yields were found to be more (4.1 t ha^{-1}) in mild sloped land. The steep slopes showed 25% loss in productivity due to land degradation compared to mid- and mild-sloped land.

Table 2. Crop Yields (t ha^{-1}) as varied with a location on a toposequence, Tan Ha watershed, Vietnam.

Crop	Year	Toposequence Top	Middle	Low
Maize	1999	4.2	5.4	4.9
	2000	5.1	5.7	5.5
Groundnut	1999	1.7	2.1	2.4
	2000	2.7	2.8	3.1
Soybean	1999	0.75	1.1	1.03
	2000	1.4	2.3	2.8
Mungbean	1999	–	1.2	0.95
	2000	0.52	0.72	1.24

The varying soil depth in a research scale watershed at ICRISAT, Patancheru, India, provided an excellent opportunity to quantify the yield losses due to reduced soil depth. The results (please see Table 3) revealed that rainy season soybean yielded 120 kg ha^{-1} less in shallow (< 50 cm soil depth) soil than that of the medium depth (> 50 cm soil depth) soil. However post-rainy season chickpea which is grown on stored soil moisture suffered more by producing 338 kg ha^{-1} less grain yields on shallow soils (Table 3). The total systems productivity in medium deep soils was more and the increase in productivity over shallow soils was 434 kg ha^{-1} more in shallow soils in soybean-chickpea cropping system.

Table 3. Average grain yield (kg ha^{-1}) in Vertic Inceptisol watershed at ICRSIAT during 1996–2001

Soil depth	Land-form	Sole soy-bean	Chick-pea	Total systems produc-tivity	Inter-cropped soybean	Pigeon pea	Total Systems Produc-tivity
Medium (≥ 50 cm)	Flat	1722	933	2656	1398	905	2302
	BBF	1793	1100	2893	1343	882	2225
Shallow (< 50 cm)	Flat	1660	658	2319	1250	821	2071
	BBF	1662	701	2363	1268	934	2201
SEM	First crop	87.6					
	Second crop	103.4					
	Total system	157.7					

In order to quantify the effect of soil degradation in terms of reduced productivity through the effect of field location on a toposequence in the watershed, soil samples on a toposequence to a depth of 1m were characterized. This study would also help in identifying the suitable indicators for soil degradation in the watershed. Soil biological parameters such as microbial biomass, soil respiration, dehydrogenase, alkaline and acid-phosphatase activities are the direct measures that indicate soil health. Microbial biomass C and soil respiration varied significantly for the soil samples from a toposequence. Biomass C and respiration values for top 10 cm samples from top of the toposequence were similar to the values of the 10–20 cm samples of the middle part of the toposequence.

Detailed soil parameters from such a study enable us to relate the indicators of soil degradation with the crop productivity for estimating the productivity losses due to degradation. Variation in soil biological parameters along the toposequence and soil depths for soils of Thanh Ha watershed in Vietnam and Adarsha watershed in Kothapally, India were studied (please see Table 4). These results showed in soils of Vietnam watershed, which receives on an average 1300 mm rainfall per year, the organic carbon content was twice that of Kothapally watershed, India with 800 mm rainfall per year, however microbial biomass C in both the watersheds was similar.

Table 4. Soil biological properties along the toposequence in Adarsha watershed, Kothapally, India and Thanh-Ha Watershed, Vietnam.

Soil property toposequence	Soil depth (0-105 cm) Thanh Ha, Vietnam	Adarsha, A.P., India
Microbial biomass C (mg C kg^{-1})		
Lower	107.5	114.9
Middle	112.2	122.3
Top	124.9	136.7
SEM	8.57	9.71
Microbial biomass N (mg N kg^{-1})		
Lower	11.16	9.48
Middle	10.14	9.05
Top	16.35	12.04
SEM	1.986	0.913
Mineral N (mg N kg^{-1})		
Lower	18.96	7.17
Middle	17.62	6.79
Top	11.83	7.86
SEM	1.825	0.971
Net N mineralization (mg N kg^{-1} soil 10 d^{-1})		
Lower	9.18	4.77
Middle	7.81	4.45
Top	10.31	5.33
SEM	0.037	0.511
Organic C (mg C kg^{-1})		
Lower	8517.0	3973.0
Middle	8233.0	4300.0
Top	9633.0	5473.0
SEM	795.7	494.3

Strategies to Combat Land Degradation

The approach of integrated watershed management is quite significant to address the issues of land degradation. This attempts to bring about desirable changes in a more holistic and systematic way to various watershed systems. This approach covers wide-ranging aspects like health of the land such as farming systems, agro-forestry, infrastructure development, soil and water conservation and community participation. Watershed management is defined as an integration of technologies within the natural boundaries of a drainage area for optimum development of land, water and plant resources to meet the basic needs of the people in a sustainable manner. Watershed management solutions must address the problem of rural poverty, protect the natural resources and rehabilitate degraded areas, particularly those that pose hazards to human life and welfare. The approach yields encouraging results in terms of improving the overall condition of land resources. The way forward is to conserve rainwater, reduce land degradation and replenish the impoverished soil through renewable resources such as biological nitrogen fixation, improved crop combinations and management, which will result in sustained productivities and improved livelihoods of the poor farmers of semi-arid tropics.

The watershed based research was initiated at ICRISAT with the following objectives, to increase the productivity and sustainability of the medium and high water holding capacity soils in the intermediate rainfall region and also to develop environment-friendly resource management practices that will conserve soil and water resource. The countries, which are targeted, are Central India, Northeastern Thailand and Northern Vietnam, where the annual rainfall is 800–1300mm. The soils here are having medium to high water holding capacity (150-200 mm).

Participatory watershed management is a process, which aims to create a self-supporting system essential for sustainability and development. The process begins with the management of soil and water, which eventually leads to the development of other resources. People's participation is critical for sustainable development and management of watersheds. Lack of involvement of people in the past in the management of watersheds has been a major hindrance in sustaining whatever conservation measures have been adopted. Over the years it was realized that community participation is must for sustaining watershed approach as a model for development. Human resource development and large-scale community participation is essential since finally it is the people who have to manage their resources. People's or farmers participation is the key to success of any integrated watershed development program.

Current Model of Watersheds Research at ICRISAT

The current model of watershed management research pursued at ICRISAT involves all the above said environment-friendly options along with the concept of linking strategic research conducted at on-station watersheds with the on-farm development research conducted in partnership with farmers through national agricultural research systems (NARS) and with the direct assistance of non-governmental organizations (NGOs). The on-farm watersheds are technically supported through a consortium approach and emphasis is on empowering the farmers through capacity building.

Operational scale watersheds are in operation since 1976 in ICRISAT which are used to conduct strategic soil, water and nutrient management (SWNM) research to study the sustainability of the systems, collection of data to develop and validate new simulation models, construct detailed budgets for water, energy, and nutrients and also to study the long-term effects on natural resources through integrated watershed management approach.

Vertisols are deep heavy black soils with a texture of clay, clay loam or silty clay loam. Vertisols have high moisture retention capacity and they become very hard and cracked when dry and sticky when wet and cannot easily be handled under either conditions. Traditionally Vertisols are left fallow in rainy season and are cropped in the postrainy season on stored soil moisture. With this traditional fallowing, Vertisols are prone to severe erosion and are under utilized for their production potential. These long-term operational scale experiments at ICRISAT have given an excellent opportunity to validate the hypothesis that improved systems on a whole increased crop growth, crop production and carrying capacity of the land and increased soil quality and carbon sequestration in Vertisols.

Vertic Inceptisols occur in association with Vertisols on a toposequence. These soils have similar physical and chemical properties as the Vertisols, except that these are shallower and somewhat lighter in texture and occur on slopes not exceeding 5%. Because of their location on toposequence, Vertic Inceptisols are prone to severe land degradation. Major constraints for crop production on these soils are a high runoff of rain water and associated soil erosion, depletion of nutrients and beneficial organisms leading to decline in crop productivity. At ICRISAT, Patancheru, studies on crop productivity and resource use of a soybean-chickpea sequential and soybean/pigeonpea intercrop systems on two landforms (BBF and flat) and two soil depths (shallow and medium-deep) at watershed scale on a Vertic Inceptisol were taken up.

Real-World On-farm Watersheds

To scale-up the benefits of integrated watershed management observed at research stations to the real world on-farm watersheds, the approach followed is in a participatory mode in Asia. This was undertaken within a project "Improving Management of Natural Resources for Sustainable rainfed Agriculture" funded by Asian development Bank. All the on-farm technology evaluation trials are conducted on benchmark watershed sites in partnership with farmers and the on-farm watersheds vary from 30–10,000 ha with varying agro ecological potential. Currently, we are evaluating the model of technical backstopping the on-farm watersheds, which are planned, developed, and monitored in partnership with NARS, NGOs and farmers using new science tools. Five on-farm watersheds in India, Thailand and Vietnam are in operation.

The model followed adopts a multidisciplinary and multi-institutional consortium approach for technical backstopping the development projects. "Islanding approach" is the strategy for pursuing a strategy of linking strategic research done in micro-watersheds within a community watershed with applied on-farm research to provide mechanisms to effectively transfer natural resources management technologies to farmers. Holistic farming systems approach to sustain productivity and to improve land and environment quality is adopted. Women are usually the critical group involved in decision-making regarding natural resources management. At the village and community level women have been empowered through group training. Continuous monitoring and impact assessment is taken as an integral part from the early stages.

Two on-farm watersheds one in India and another in Vietnam are described in this paper as case studies.

Baseline Data of the Indian Watershed Under Study

Adarsha watershed, at Kothapally, India is one of the benchmark sites and is located at Longitude 78°5' to 78°8' East and Latitude

17°21' to 17°24' North in the Ranga Reddy district of Andhra Pradesh. The landscape of the watershed is made up of Vertisols and associated Vertic soils (90% of the area); Alfisols (10% of the area) are also present. The main rainy season crops grown are sorghum, maize, cotton, sunflower, mungbean, and pigeonpea. In the postrainy season sorghum, sunflower, vegetables and chickpea are grown. Wheat and Rice are also cultivated to some extent. The annual rainfall of Kothapally area is about 800 mm received mainly in June to October (85%). About 25-30% of the rainfall is lost as runoff carrying away the fertile topsoil.

In this watershed, the total irrigable area was very less and no single water harvesting structure for human and animal use was seen in 1998 i.e., at the start of this project. Large area is under rainfed farming in this village. The M Venkatarangaiya foundation (MVF) a non-governmental organization, Drought Prone Area Programme (DPAP), Government of Andhra Pradesh and ICRISAT jointly selected this watershed in Shankarpally Mandal, Ranga Reddy District for evaluating the integrated watershed management option for improving rainfed agricultural production. This could be achieved through integrated watershed development for reducing poverty of the farmers and increased systems productivity. In Partnership with the farmers a micro-watershed was selected with an area of 30 ha for evaluating integrated watershed management options. The watershed is equipped with hydro meteorological equipments and is also monitored for inputs, outputs, productivity, incomes etc., for preparing detailed budgets for water and nutrients at catchment level.

All the activities in the watershed are planned, executed and evaluated by the farmers through watershed committee and watershed association. These prime committees form further sub-committees for specific activities such as sites identification for check dams, farm ponds, for identifying farmers to evaluate the improved options. A system of social auditing is also an integral part of the integrated watershed development activity.

During rainy season, Vertisols suffer with the problem of waterlogging, in order to alleviate these problems, various water and soil conservation practices have been investigated in India to control the flow of excess rain water, thereby minimizing soil erosion and increasing infiltration. Provisions were made to take excess water out of the fields safely and collect in tanks, which can be used either for supplementary irrigation or for recharging the groundwater.

Baseline Data of the Vietnamese Watershed Under Study

The second watershed under discussion in this paper is Thanh-Ha watershed located in Kim Boi district of Hoa Binh Province of Vietnam. The climate here is monsoonal with hot, wet summers and cool, cloudy moist winters. The total rainfall is 1300-1800mm per annum Northern Vietnam has four distinct seasons: Spring (February-April), summer (May-July), autumn (August -October) and winter (November to January). Although ten different crops are grown in the watershed, major crops in terms of cropped area were: maize (83%), sugarcane (8%), legumes (13%) and watermelon (6%). Groundnut was grown on large area in the past but went out of cultivation due to severe problem of pod rot disease. Soybean which is popular legume elsewhere is not cultivated in the watershed. Cereal monocropping (maize- maize) is predominant and occupied 77% of the cultivated area in 1998. Cereal-legume cropping is only 2-3% of total cultivated area. Watermelon- maize cropping system is also popular (11%).

The most common soil type is the red-yellow ferralitic. These soils accumulate iron and aluminum to form laterite. Mineralization is rapid, and organic substances quickly break down, resulting in low humus content. Intensive surface cultivation and deep leaching processes make the soil very acidic and poor in nutrients. Nitrogen, phosphate and cations are easily dissolved or carried away to such an extent that these soils cannot be cultivated for long before they suffer serious degradation. In extreme cases of erosion, a hardpan of laterite nodules is exposed. Soils were analyzed to a depth of 1.5 m and also based on the toposequence for physical and biological properties. Soil is medium Loamy in texture, acidic in nature with very poor organic matter, medium potassium and very low phosphorous content. Since the soils have very low organic matter and P, they are more suitable for industrial crops (tea) and fruit crops (litchi) than annual crops (maize and legumes). Soils need organic and inorganic supplements and particularly P fertilizer for good productivity.

Agricultural extension organizations like Agriculture Department Hoa Binh province, Research and Development organizations like Vietnam Agricultural Research Institute (VASI), and International organizations like ICRISAT are involved in the day to day activities of the watershed.

Findings From the Case Studies

Soil and Water Conservation Measures

Main focus of watershed activities is to conserve natural resource base in the catchment and use it efficiently for sustaining productivity. Various conservation measures at farm level and community level are planned and undertaken. Various farm-based and community-based soil and water conservation measures are adopted to reduce on-site soil, water and nutrient losses. The conservation of soil and water resources in the sloping land ecoregions of Vietnam has not been followed for too long. Thorough understanding of constraints and developments of appropriate technology with focus on land and water management will help in optimizing food production and arrests further land degradation. Watershed based technologies offer excellent opportunities for sustainable agriculture and water development in sloping land ecoregions. The strategic goal of watershed research here is sustainable agricultural development by reducing land degradation and alleviation of poverty.

Farm-based soil and water conservation measures like land forms; broad-bed and furrows, ridges and furrows, and contour planting at Kothapally and in Vietnam ridge and furrows and contour planting were adopted. Field bunding in 47 ha is completed at Kothapally and vegetative bunds are formed in both the watersheds. Plantation of Gliricidia (30,000 plants in 1999 and 16,000 plants in 2000 in Kothapally and 15000 plants in Vietnam) on the field and property bunds to stabilize bunds, conserve rainwater and soil, and to produce N rich organic matter. In Vietnam, exotic grass species (Brachiaria ruziziensis) having high nutritive value and good adaptability was introduced in the grass ways and on field bunds to reduce runoff velocity, soil erosion and to serve as good fodder for farm animals. In Vietnam, staggered trenches, silt traps were dug to capture rainwater, to reduce the velocity of runoff and to increase time for infiltration.

Community-based soil and water conservation measures like grassed waterways, water storage structures four in Kothapally, one earthen and 3 masonry were constructed with a capacity of 300 to 2000m^3. In Vietnam, three water structures with a capacity of 40m^3 were dug and they serve as recharging tanks. 47 gully control structures were constructed at Kothapally. Wasteland development was undertaken by contour trenching, planting horticultural and agro forestry plants, and developing grasslands. Gabion structures were constructed at Kothapally. Along with water harvesting for enhancing water use efficiency, several improved land, crop, pest and nutrient management options along with soil conservation measures were taken up and all of these together made farmers reap rich rewards.

In Vietnam, low temperature and moisture stress are important production constraints in groundnut during the winter season. The effect of plastic mulch on moisture conservation and soil temperature was assessed. Plastic mulching gave higher pod yields over no mulch in groundnut. Improved cropping systems with high-yielding stress tolerant crop cultivars were introduced into the watersheds. Bullock drawn tropicultor is used for sowing and fertilizer application.

Improved Nutrient Management Options

At Kothapally and Vietnam, planting Gliricidia on field property bunds was taken up and this supplies biologically fixed N through incorporation of loppings to the crop and reduces the usage of fertilizers. Balanced nutrient doses were used for sustaining productivity in these watersheds. *Rhizobium* inoculation of pigeonpea and soybean seeds was done to increase biological N2 fixation. At Kothapally, Vermi-composting using weeds, earthworms and rock phosphate is practiced by women farmers and this is under serious consideration at Vietnam. Positive crop responses to specific amendments based on soil analysis e.g., boron and sulphur application were observed at Kothapally. In Vietnam, Improved nutrient management practice (180 N: 90P_2O_5: 90K_2O; 10 t FYM; 400 kg lime ha^{-1} and biofertilizer) was compared with farmers' practice (200-250 N: 80-85P_2O_5: 45-50K_2O kg ha^{-1}) in maize with an objective to wean the farmers away from high dependence on inorganic fertilizers and encourage balance fertilization. Higher grain yields were obtained with improved practice (5.2 t ha-1) in the second consecutive year and indicated considerable scope for savings on N fertilizer. Application of bio-fertilizer in groundnut resulted in 19.8% higher pod yields (2.1 t ha^{-1}) over no bio-fertilizer (1.7 t ha^{-1}) application. Quantification of BNF using N-difference method is being done using non-fixing crop (maize and sesame) varieties of matching duration with groundnut and soybean in farmers' fields. In Vietnam, farmer managed micronutrients trials were initiated. Straw burning in maize is being discouraged and farmers were given training to use the straw either for soil incorporation or as mulch in young fruit trees.

Improved Pest Management Options

IPM is a way of controlling pests using a variety of techniques. The outcome of a sound IPM program is usually increased profits due to savings from reduced pesticide application and increased protection of the environment. Insect pests continue to be the major problem in pulse production in Asia. Intensive use of pesticides leads to total crop loss. Complete dependency on chemical control for the past three decades led to unsatisfactory pest management along with environmental degradation.

ICRISAT along with NARES and NGOs in both the watersheds along with the farmers conducted research to identify environmentally sound and economically viable plant protection technologies which reduce yield losses and improve the income to the farmers. Farm surveys and participatory rural appraisals identified the non availability of IPM components such as plant-based products, nuclear polyhedrosis virus (NPV), pheromones and high pest tolerant varieties. The farmers harvested six fold increased yields through better management of pests by controlling them with neem seed extract and there is a 6–100% reduction in pesticide usage. After thorough evaluation of the existing pest management options, a comprehensive integrated pest management package for chickpea and pigeonpea has been developed and evaluated in farmer participatory approach mode. Revitalizing the effective indigenous methods like shaking of pod borers from the pigeonpea crop and use of neem for pest management is done in both the watersheds. These indigenous methods are effective, cheaper and environment-friendly.

Productivity Gains and Sustainability

At Kothapally, Farmers evaluated improved management practices such as sowing on a BBF landform, flat sowing on contour, and fertilizer application, treatment along with *Rhizobium* inoculations and using improved bullock drawn tropicultor for sowing and interculture operations. Farmers obtained two-fold increase in the yields in 1999 (3.3 t ha^{-1}) and 2.5 fold increase in 2000 (3.7 t ha^{-1}) as compared to the yields of sole maize (1.5 t ha^{-1}) in 1998 (Table 5). In case of intercropped maize with pigeonpea improved practices gave a four fold increased maize yield (2.7 t ha^{-1}) compared with farmers practices where the yields were 0.7 t ha^{-1}. In case of sole sorghum the improved practices adopted increased yields by three-fold within one year.

Table 5. Average crop yields from on-farm evaluation of improved technologies in Adarsha watershed, Kothapally, 1998, 1999 and 2000

Crop	1998 Baseline	Yield (kg ha^{-1})	
		1999	2000
Sole maize	1500	3250	3750
Intercropped maize	-	2700	2790
(Farmers' practice)		700	1600
Intercrop pigeonpea (Farmers' practice)	190	640	940
Sole sorghum	1070	3050	3170
Intercropped sorghum	-	1770	1940

In 1999-2000, farmers achieved highest systems productivity, total income and profit from improved maize/pigeonpea and improved sorghum/pigeonpea intercropping systems (Table 6). Along with the highest systems productivity the cost-benefit ratio of the improved systems was more (1:3.47) compared to the farmers traditional cotton-based systems. Cost of cultivation for the improved and traditional systems were similar, but in terms of profit gained the maize/pigeonpea and sorghum/pigeonpea intercropping systems were found to be more income yielding to the farmers when compared to their traditional systems including cotton crop (Wani, 2000).

Table 6. Total productivity, cost of cultivation for different crops at Kothapally watershed during crop season 1999-2000

Cropping systems	Total productivity (kg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Total income (Rs. ha^{-1})	Profit (Rs. ha^{-1})	C:B Ratio
Maize/pigeonpea (Improved)	3300	5900	20500	14600	1:2.48
Sorghum/pigeon pea (Improved)	1570	6000	15100	9100	1:1.52
Cotton (Traditional)	900	13250	20000	6750	1:0.51
Sorghum/pigeon pea (Traditional)	900	4900	10700	5800	1:1.18
Greengram (Traditional)	600	4700	9000	4300	1:0.92

In 2000–2001, several farmers evaluated BBF and flat landform treatments for shallow and medium depth black soils using different crop combinations. Farmers harvested 250 kg more pigeonpea and 50 kg more maize per hectare using BBF on medium depth soils than the flat landform treatment. Furthermore, even on flat landform treatment farmers harvested 3600 kg maize and pigeonpea using improved management options as that of 1720 kg maize pigeonpea grains using their normal cultivation practices (Table 7). Similar benefits from improved BBF landform and also improved management options were reported by the farmers with shallow soils and with other cropping systems. The rainfall during 1999 in this area was 559 mm which was 30 per cent below normal rainfall, and in 2000 the rainfall was 958 mm, which was 31 per cent above normal. In spite of this variation in rainfall received in 1999 and 2000 (Tables 5, 6 and 7) the productivities of the crops increased sustainably during 1999-2000 and 2000-2001.

In Vietnam, cereal monocropping (spring maize-autumn maize) is predominant in the watershed resulting in decline in soil fertility and increase in input costs. Trials to evaluate/identify improved cropping systems with soybean; groundnut and mungbean were taken up. All the cropping systems which were introduced were profitable over the traditional maize-maize cropping system indicating considerable scope for productivity gains and efficient use of natural resources. Maize double-cropping is predominant in this area before the watershed interventions. Farmers have adopted maize-legume cropping systems rather than their traditional maize-maize cropping systems, area under maize has decreased by 575 per cent. The results indicated that maize following mungbean/soybean increased yields by 25% than maize following maize. Watermelon mung-groundnut, watermelon-mung-soybean, and watermelon-mung-maize cropping systems gave highest income (201 to 268%) over the traditional cropping system (Table 8). Usage of plastic mulches resulted in doubling the yields (1.5 t ha^{-1}) than the control (0.7 t ha^{-1}) treatment. Environment-friendly and economically feasible straw mulches increased yields by 71 percent over the no-mulch fields. Application of both these mulches have increased pods plant and pod weight parameters (Table 9).

Table 7. Productivities in different on-farm trails at Kothapally during 2000-2001

System	Soils	Land-form	Yield (kg ha^{-1}) (1)	(2)	Total systems productivity (1+ 2)
Maize/PP	Shallow	BBF	1750	380	2130
Maize/PP	Shallow	Flat	1680	290	1970
Maize/PP	Medium	BBF	2830	1070	3900
Maize/PP	Medium	Flat	2780	820	3600
Maize	Medium	BBF	3000	-	3000
Maize	Shallow	BBF	2030	-	2030
Sorghum	Medium	BBF	3000	-	3000
Maize/PP	(Local farmers practice)		1490	220	1710
Sorghum/ PP	(Local farmers practice)		470	115	585
Sorghum	(Local farmers practice)		1010	-	1010

1. Main crop (Maize/Sorghum)
2. Component crop (Pigeonpea)

Table 8. Net income (US $) from various cropping systems, 1999-2000

Cropping system	Net Income (US $)	Additional profit over traditional system (US $)	% Increase over traditional system
Maize-maize (traditional system)	492	–	–
Maize-soybean	746	254	51
Maize-groundnut	780	288	58
Watermelon-maize	1453	961	195
Groundnut-maize	825	333	68
Groundnut-soybean	1079	587	119
Soybean-groundnut	1102	610	123
Soybean-maize	814	322	65
Soybean-soybean	1068	576	117
Mungbean -soybean-maize	773	281	57
Watermelon-mungbean-maize	1481	989	201
Mungbean -soybean-groundnut	1106	614	125
Watermelon-mungbean-groundnut	1813	1321	268
Mungbean-soybean-groundnut	1130	638	130
Watermelon-mungbean-soybean	1803	1311	266

Table 12. Effect of straw and plastic mulch on groundnut yield parameters in Thanh Ha watershed, summer 2000

Treatment	Pods plant^{-1}	Pod mass (g)	Test weight (g)	Pod yield (t ha^{-1})	Total dry matter (t ha^{-1})	Shelling (%)
No mulch	11.9	109.9	41.2	0.7	5.38	66.8
Straw mulch	14.5	113.7	43.8	1.18	5.88	65.8
Plastic mulch	13.6	118.1	46.2	1.54	6.32	68.3
NA1	15.7	107.1	42.6	1.03	6.14	66.7
NA 5000	14.3	108.7	41.5	0.97	6.9	65.7
SEM	0.62	1.97	0.91	0.12	0.25	0.5
CV %	9.9	3.9	4.7	22	9.9	1.5

Monitoring and Impact Assessment

To know the impact of watershed management continuous monitoring of all the parameters is done.

- *Crop productivities*: Productivities are recorded for every crop in every year as described in the previous sections and impact is assessed.
- *Nutrient budgeting*: Studies on optimum doses of fertilizers to have balanced nutrient budgets.
- *Weather*: An automatic weather station is installed to continuously monitor the weather parameters.
- *Groundwater*: To monitor the groundwater levels, open wells in the watershed are geo-referenced and regular monitoring of water levels is done.
- *Quantification of BNF* in farmers' fields using N difference method and 15N isotope dilution method.
- *Runoff and soil loss*: Runoff, soil and nutrient losses are monitored using automatic water level recorders and sediment samplers.
- *Satellite monitoring*: Changes in cropping intensity, greenery, water bodies and ground water levels are monitored, GIS maps indicating soil types, soil depths, crops grown during rainy and post rainy season have been prepared.

Improved Greenery

The NDVI has been used to monitor the impact of the implementation of action plan. An increase in the vegetation cover, which reflects an improvement in the vegetation cover was observed. The spatial extent of moderately dense vegetation cover, which was 129 ha in 1996, has increased to 152 ha by 2000 in Kothapally.

Increased Levels of Groundwater and Decreased Runoff

Hydrological investigations of the existing wells in the watershed indicated a rise in ground water table levels (5–6 m) at Kothapally (Figure 2). The Runoff was decreased in the watershed area. At Vietnam, the groundwater table was found to be increased by 1 m. (Figure 3) near percolation tanks.

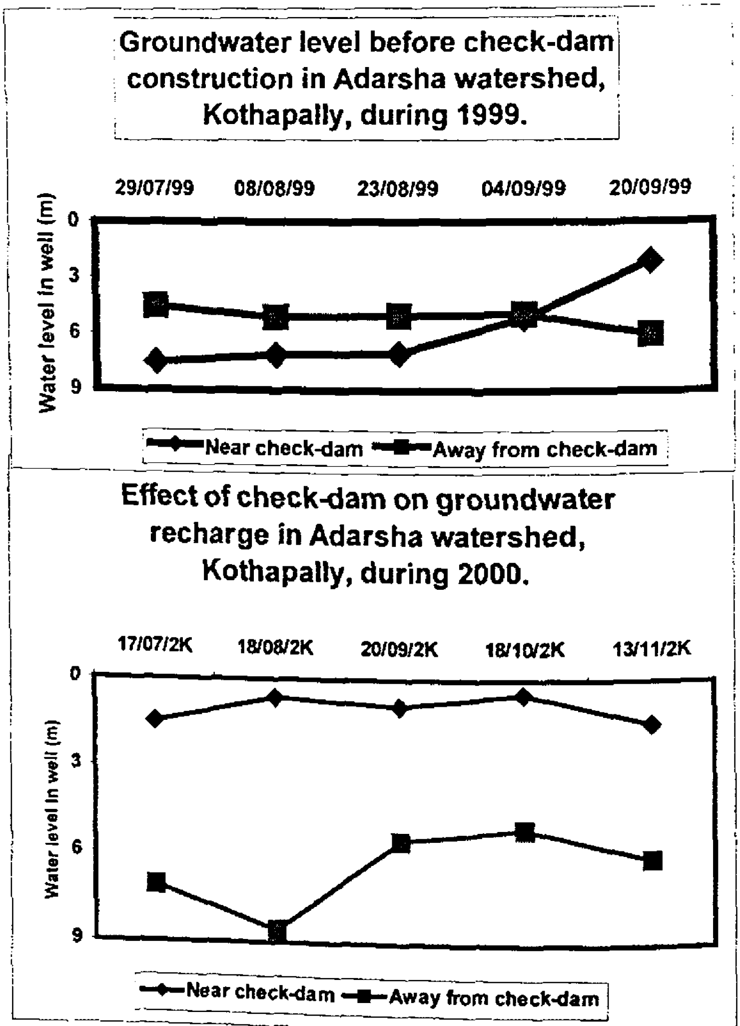

Figure 2. Level of groundwater table before and after the construction of check-dam at Kothapally watershed, India

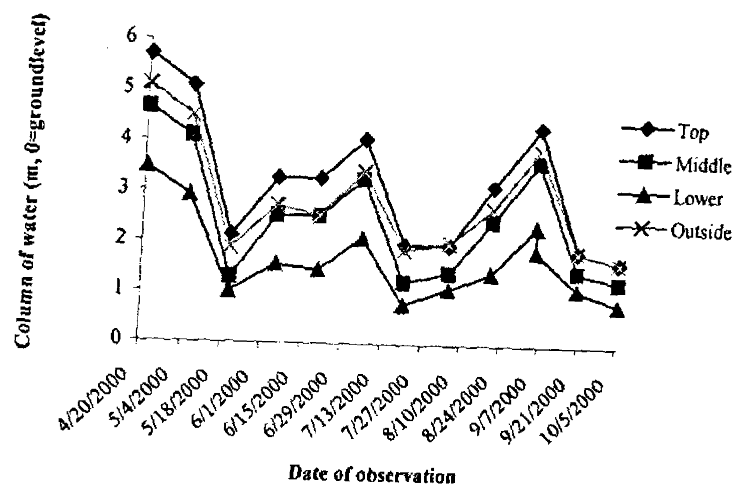

Figure 3. Groundwater table fluctuations in Thanh-Ha watershed, Vietnam

Decreased Runoff and Soil Loss

In the Thanh Ha watershed, with annual rainfall of 1349 mm in the year 2000, runoff recorded was only 29.6 percent of the rainfall. The total soil loss from the watershed in 2000 is 6.8 t ha^{-1}.

Human Resource Development

Human resource development is an important component of integrated watershed management model is to train the farmers and to empower them to take appropriate measures through enhancing their knowledge. Farmers are exposed to new methods and knowledge for managing natural resources through training, video shows which provide information, and field visits to on-station and on-farm watersheds. Educated youth are trained in skilled activities such as NPV production, vermin-composting etc. Micro-watershed within the main watershed serves as "an island" for learning from the farmers. Special emphasis is given to educate and expose the women farmers to new management options. The technical backstopping team is always handy to the farmers for clarifying their doubts and seeking more information at their location. Farmers and landless families are trained and encouraged to undertake income generating activities in the watershed which can be of help to sustain the productivity at catchment/watershed level.

Conclusions

Integrated watershed approach enables to have "win-win" situations for sustaining productivity and reducing land degradation which are the main causes of poverty in the rainfed areas of Asia. Current model of watershed research followed at ICRISAT links on-station research to on-farm and adopts the consortium approach by technical backstopping. Farmer participatory approach in on-farm research was successful in the area of SWNM research. Integrated watershed approach is the way for sustaining productivity, minimizes land degradation and reduces the poverty in rural Asia. The current model of ICRISAT watershed approach seems to have very high potential for bringing favorable changes in drylands of the semi-arid tropics. On-farm watersheds managed through community participation could sustain productivity of drylands and preserve the quality of the land resources and environment in the SAT. Holistic systems approach through integrated watershed management can result in sustainable management of land resources and achieving food security in the semi-arid tropics.

Acknowledgements

This report is based on the research conducted at benchmark sites in India, Thailand and Vietnam through the project RETA 5812 : Improving Management of Natural Resources for Sustainable Rainfed Agriculture funded by the Asian Development Bank, Manila, Philippines, RETA 5812. The financial assistance provided by the ADB is gratefully acknowledged. At all the benchmark sites teams of scientists from Research institutes, NARS, NGOs are involved in undertaking this research and whose efforts are thankfully acknowledged.

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Summary Report of the Workshop

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Workshop Overview

The 4th International Workshop: "Integrated Land Management in Dry Areas" was organized by the United Nations University (UNU) in cooperation with the Chinese Academy of Sciences (CAS). The Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) of the CAS served as the local host. The workshop was also supported by UNESCO and the International Center for Agricultural Research in the Dry Areas (ICARDA).

The workshop comprised a two-day field investigative excursion in the Naiman area, followed by two and a half days of technical sessions in Beijing including paper presentations and discussion. The field excursion was hosted by the CAS and also supported by the forestry department and a number of local government agencies based in Naiman. The Naiman Station for Desertification Research (NSDR) of the CAREERI served as the main local host.

Summary Report of the Field Excursion

Day 1: Sunday, 9 September 2001

Horkin Sandy Land (Bagaborihe)
(Photographs B and C)
This dry area receives an average rainfall of 340 mm each year and has suffered drought for the past two years when the average rainfall dropped to 200 mm (evapotransportation is estimated to be 1900 mm per year). The natural vegetation in this region was destroyed in the 1960's and 1970's due to climate change and human impacts. The result is moving and shifting sand dunes (about 10 m per year for smaller dunes) that threaten existing infrastructure such as roads. The fixation of moving sand dunes using a variety of dune control methods, including corn-stem checkerboards and living fences, was demonstrated here. These dune fixation schemes appeared to be quite successful and some natural re-growth of vegetation was visible. Other livelihood activities include cash crops like maize, millet and beans. Grazing in the region is prohibited to enhance vegetative growth. Please refer to Chapter 6 of this book by Xueyong *et al.* for a more detailed description of the research findings.

West Lake
(Photograph D)
This lake was originally recharged by groundwater, with a total capacity of 500 million m^3. However, at the time of the visit the lake had dried up completely due to falling water table in the region. This effect can be correlated to excessive withdrawal of groundwater, where water levels have been dropping at the rate of 2.7 m per year.

Hailasu Village
(Photograph E)
This village is a model of comprehensive and sustainable control of desertified land. It has a population of 1,200 and a cropland area of about 220 hectare. This village was completely desertified by 1992 and the average annual income of the local villagers had dropped to 430 Yuan per person per year. An ecological construction model was implemented in 1992 in which about 1,300 ha were converted to improved and productive sandy lands and about 900 ha were afforested. By the year 2000, the crop production had doubled that in 1992 and the average annual income increased to 3,900 Yuan per person. At the moment, each household has about 1/3 ha and maize is the staple crop grown (ave. yield = 9 tonnes/ha).

Yaoledianzi Village
This village has been NSDR's demonstration area from 1985. Under a multi-faceted approach, this village has progressed significantly on rural economic development and ecologically-sound environmental construction. As part of NSDR activities, different crops like wheat and maize were introduced, in addition to the traditional crops of sorghum and millet. Sand dune fixation was carried out by the checkerboard method. A village committee was formed for the management of the savannah land and protection of natural vegetation from grazing was introduced; limited grazing was allowed in some areas after 3-5 years of re-vegetation. As a result of these activities since 1985, the income per capita and the grain yield per hectare have increased from 174 Yuan to 1,290 Yuan and from 1,125 kg to 4,100 kg, respectively. The moving sand dune area has decreased from 1,380 ha to 170 ha.

Grassland Experiment Site

This experimental site has also been developed by NSDR in cooperation with Japanese researchers. It contains three experimental sub-sites that study grazing, soil improvement and vegetation restoration, respectively. A range of sheep grazing experiments have been carried out at the site. These experiments are supplemented by monthly observations of changes in land cover and vegetation characteristics. Please refer to Chapter 7 of this book by Taniyama *et al.* for detailed description of the research findings.

Woodland Pine Tree Area

This is an experimental site in the vicinity of NSDR where pine trees (*Pinus sylvestris var. Mongolia*) have been planted for sand dune control. These have shown limited success in sand dune fixation.

Naiman Station for Desertification Research (NSDR)

This station has played a key role in the desertification research in semi-arid regions of China since its establishment in 1985. The facilities include several laboratories for carrying out measurements (such as micrometeorology, biomass measurement, chemical analyses and soil analyses) and a library containing relevant reference materials. It has pilot-scale field sites where water balance and soil nutrient cycles can be studied. It also contains a weather station that can measure soil transport and deposition in addition to the typical meteorological parameters. The activities by NSDR earned it the UNEP Prize of 'Saving the Drylands' issued under the UNEP-IFAD Joint Programme for Success Stories, 1997-98.

Day 2: Monday, 10 September 2001

Xinglungzhao Forest Station

(Photographs F and G)

This forest station has two major components: afforestation for windbreaks in a desertified land and household-level management of integrated farmland. The total planted area at this forest station is about 18,700 ha (which will be eventually increased to about 21,000 ha by the year 2006). The main source of water is the local aquifer, which is supplemented by irrigation water. There are 65 major and 412 small wells for extracting the groundwater; water table depth is about 4-5 m in this area. The annual increase in the timber in the forested area is estimated to be 12,000 m^3. The plantation was developed by the government and the farm area is managed by local farmer families with a 30-year lease.

Meng Jiadin Reservoir

This reservoir is fed by the Xi Dao river and it serves the local needs for irrigation water. Its capacity is about 120 million m3. It is located in close proximity of the forest station we visited.

Presentation of Desertification Control Activities in the Naiman Region

A detailed presentation of the desertification control activities carried out in the Naiman region was provided by Mr. Li Huifang, Vice Governor of the region. The presentation made by him is provided here. This session also provided an opportunity for an in-depth discussion with researchers at NSDR and local officials.

Introduction of the Comprehensive Desertification Control in Naiman

Vice governor: Li Huifang
(028300, Naiman County Government, Tongliao municipality, Inner-Mongolia, China)

1: Background

Naiman, from E120° 19'40" to 121° 35'40" and N42° 14'40" to 43° 31'20", is located in the center of Horqin Sandy Land. It is adjacent to Chifeng municipality on the west and Liaoning province on the south. It covers a total area of 816,000 ha, of which 115,000 ha is cropland, 413,000 ha grassland and 240,000 ha forest and woodland. It covers 21 townships and 529 villages. The total population is 420,000. The annual revenue in 2000 was 62,500,000 RMB (about US$ 7,560,000) and the averaged income of the farmers and herdsmen is 1264 RMB per person (about US$150).

Naiman is in the area of north semi-arid temperate continent climate zone. The monthly mean air temperature is 6.1-6.4°C and the frost-free period is 146-151 days a year. The long-term annual mean precipitation falls in the range of 350-450mm and most in the period of June to August.

Naiman has a unique landform and it is rich in tourist resources. There stretches sinuously the mountain in the south, sand in the middle part and large area of grassland in the north. Two tenth of the land is mountain, six tenth is sandy land and two tenth is plain. There are seven river systems and five reservoirs in this county. The total area of pools for fishery is 13,000 ha, and about 20 species of fish are raised, including carps and crucian. The Mengjiaduan reservoir and Shelihu reservoir are two desert reservoirs. The palace of local Mongolian king and the tomb of Cheng kingdom Princess in Liao dynasty (A.D 907-1125) have been well preserved.

Naimanqi is also rich in mineral reserve with a promising exploitation potential. The Chinese medical stone, limestone and marble are called 'Naiman Sanshi' or 'three Stones in Naiman', of which the Chinese medical stone is one of the most famous medical stones in the county. It has a reserve of 50,000,000 t. The total reserve of limestone is 220 m tonnes. The silica reserve reaches at 30 b tonnes. Licorice, ephedra and bulrush are named as 'Three Naiman Treasures.' The production of ehpedra and licorice is 1,500,000 kg and 600,000 kg, respectively.

There is a great potential for agricultural development in this county. The total grain product was 0.5b kg in 2000. The crop includes 20 species. This county is one of important grain production areas in Inner Mongolia. Both of the Naiman seed melon and Naiman millet are famous brand in Inner Mongolia. The seed melon production is 20 m kg and the millet is 50 m kg in 2000. There is a good thrust in the industrial development in this county. An industrial system, dominated with agro-pastoral product finery, wood process and construction material production, is well developed with striking local and national characteristics. Alcohol, Chinese medicine stone, glasses, cement and sandy brick, as well as artificial wood plate, woolen products and new railway castings are important products in this county.

2: Desertification Control and Efficient Use of Land Resources

Naimanqi is an area dominated with mountain and sandy land, covering more 80% of the total land. In the past decades, especially in the period of 1960's and 1970's, with the increased population and simply pursuing economic benefit, predatory exploitation of land resource, such as over-cultivation, over-grazing and over-cutting prevailed over this county. As a result, large area of grassland and cropland were desertified due to severe wind erosion. Research showed that desertified land in 1982 reached at 572,000 ha, and water eroded land hit the figure of 668,000 ha. The deteriorated environment, in turn, imposed severe impacts on farming and livestock raising.

Concerned with the increasingly frequent natural disasters, together with county committee, the county government attached great importance on to desertification control and initiated the afforestation project at Xinglungzhao (Forest Station) in 1976. The project covered an area of 52,600 ha, stretching 44 km from east to west and 12 km from south to north. Administratively, it includes seven townships, five forest plantations and one reservoir. Among the 52,600 ha land, there is about 38,400 ha sand land and 14,300 ha inter-dune land. Till the 1980s, 32 large shelterbelts and 291 small shelterbelts were set up with 14 main belts of 500 m width stretching 212 km and 1044 accessory belts of 100 m width ranging 992 km established. Totally, the afforested land increased to 24,000 ha effectively controlling about 51,200 ha desertified land. As result, this project made a great achievement in ecological improvement, economy development and poverty relief with increase of forest cover from 1.5% to 45.6%.

Based on the successful experiences of Xinglungzhao to halt desertification radically, the county government adopted 'planting trees and grasses, and comprehensive managing the mountain and sand land and rational utilization of water resources' as the basic guiding principles in 1982. Some 20 years later, about 260,000 ha of desertified land and 418,000 ha of water eroded land were improved.

In 1998, ecological construction, commonly referred to as desertification control, was defined as a 'lifeline' of Naiman County by the county government and ecological construction was adopted in the 'Comprehensive Planning of the Social and Economic Development of Naiman County'. The county people's conference committee endorsed the plan-'Outline of the Ecological Construction in the Mountain and Sand Lands from 1998 to 2007'. The county government encouraged the people to reconstruct a new forest-Naiman within 10 years. In administration, the government advocated the 'principle of one-vote veto' in ecological construction. Then the government decided to focus on the protection of river systems at first, then to set up protecting systems for the highways. The county was classified into four sections: the south bank of Laoha river, banks of Jiaolai River, small catchments' management in mountainous area, and two sides of highways. Meanwhile, several projects for desertification control have put into action. Up to the year 2000, the forest and woodland was increased to 309,300 ha, the forest coverage increased to 26.68%. The county has planted 22,000 ha of trees in 2001.

With the above efforts, people's living and production conditions have been greatly improved and great processes made in poverty relief in this county.

Summary of Workshop Technical Sessions

<u>Tuesday, 11 September 2001</u>

Plenary and Working Session of the International Workshop

The plenary session was inaugurated through a formal opening ceremony, which included statements by Prof. Chen Yiyu (Vice president of the CAS), Prof. Motoyuki Suzuki (UNU), Dr. Wang Tao (CAREERI, CAS) and Dr. Zafar Adeel (UNU).

The opening ceremony was followed by the first technical session. The main purpose of this session was to provide a broad-brush overview of the desertification problems and challenges in China and the activities undertaken to control desertification. This was compared with similar activities in Tunisia and UNESCO-sponsored projects in other regions, particularly Kenya and Ghana. Prof. Kobori provided the historical perspective for professional relationship between Japan and China on desertification issues.

<u>Wednesday, 12 September 2001</u>

Working Sessions of the International Workshop:

The technical sessions of the workshop focused on the soil conservation problems and challenges. The primary focus was on the Chinese locations where major soil conservation challenges are encountered. These problems can be seen in the broader perspective of global warming, increasing population pressures, decreasingly available water resources and their combined impacts on the livelihoods of those living in these areas. The technical session also provided a regional overview for the East Asian region and a comparison with the situation in Uzbekistan. A companion technical session focused on the solutions for these soil conservation problems and included presentation of success stories. In addition to the Chinese case studies, a focus on Central Asian success stories was developed through papers for Uzbekistan and Tajikistan.

Thursday, 13 September 2001

Working Sessions of the International Workshop:
The final session of the workshop focused on the integrated management of all the natural resources, particularly soil, water and biodiversity. A number of examples from India, Pakistan, Jordan and China were presented where natural resource management is successfully implemented in cooperation with local communities. These included comprehensive evaluation of natural resource management in two river basins: Indus and Tarim.

The final discussion session was utilized to formulate the recommendations of the workshop.

Workshop Recommendations

Stresses in Dry Areas
Through various presentations during the workshop, the following factors were identified as the main drivers behind ecological problems in dry areas:

- Increasing population, where the rate of increase in dry areas is typically higher than the world average;
- Climatic change and variability, which impact the availability of water resources as well as other natural resources;
- Reduction of available water resources, *aridification* is a process that occurs as a result;
- Over-utilization of natural resources, typically the over-exploitation is linked to socio-economic factors prevailing in the dry areas;
- Wind erosion problems, leading to loss of valuable top soil and vegetation degradation; and
- High evapotranspiration.

Soil Conservation Issues

In order to conserve the soils, and other natural resources, in dry areas a number of critical issue areas need to be addressed. These were listed by the workshop participants as follows:

- Soil conservation should be combined with efforts for increasing productivity at the same time;
- Use of appropriate technologies for conservation of soils;
- Bridging the gap between scientific information and end-users, most importantly, the farmers in dry areas;
- Re-vegetation (w/artificial measures) is successful for sand-dune fixation and it provides opportunities for productive use of desertified lands;
- Increase agricultural diversification and avoid mono-cropping to have better genetic diversity, resistance to diseases and enhanced soil conservation; and
- Intensive agriculture, to reduce the stresses on available productive land; the following elements were identified as possible approaches towards intensified agriculture:
  a. Higher use of fertilizers
  b. Use of organic fertilizers/composts
  c. Use of secondary water (including re-use of domestic wastewaters)

Integrated Land Management Issues

In keeping with the theme of the workshop, the discussions during the field excursion and the workshop sessions focused on issues for integration of various interest areas. In order to successfully achieve such integration of land management, the following aspects were highlighted as critically important:

- Community participation in design and implementation of land management approaches is absolutely essential; this in turn requires education and awareness raising among farmers and the general public.
- Land tenure plays a key role in the integrated approaches;
- Improvements in livelihood and poverty reduction must be an essential component of the overall management approaches;
- Cultural importance of conservation should also be highlighted and sensitivity to societal and cultural

constraints must be explicitly considered in development of approaches;

- Role of women in conservation is critical, as they are most often the central stakeholder in conservation approaches;
- Water conservation and increased productivity are crucial to integrated land management; these should be tackled at both the watershed and basin-level planning;
- Stakeholder involvement in early stages of design, development and implementation of management approaches is critical to their long-term success and sustainability; and
- International cooperation is necessary to provide technical and financial resources needed for sustainable development of management approaches.

Photographs from the Workshop (Credit: Dr. Theib Oweis)

A

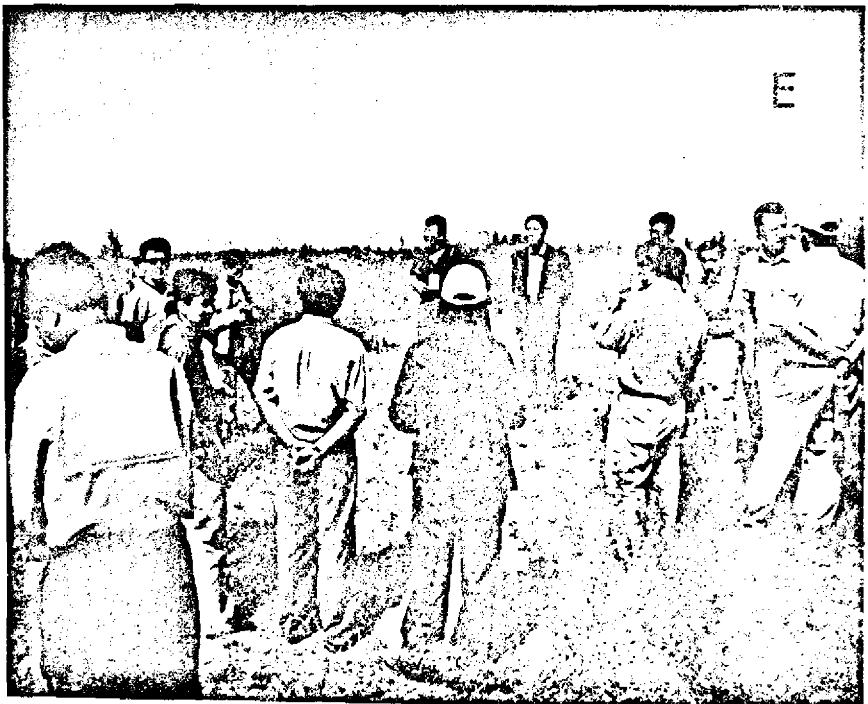
A. Workshop Participants at the Great Wall of China.

B

B. Horqin Sandy Land – checkerboard sand dune fixation is visible in the background

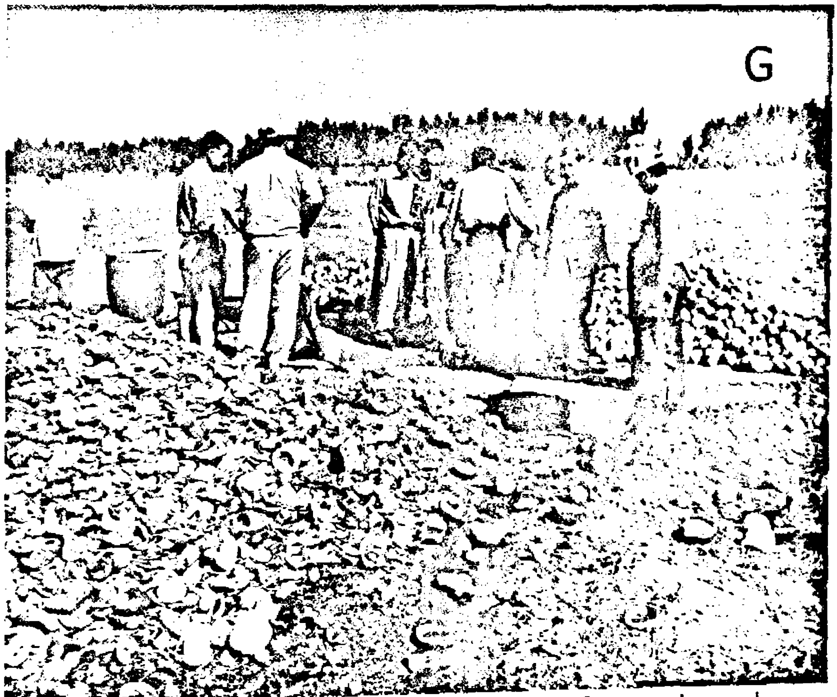
C. Checkerboard-pattern sand dune fixation scheme in the background (Prof. I. Kobori in the forefront)

D. Dried up bed of the West Lake in the background



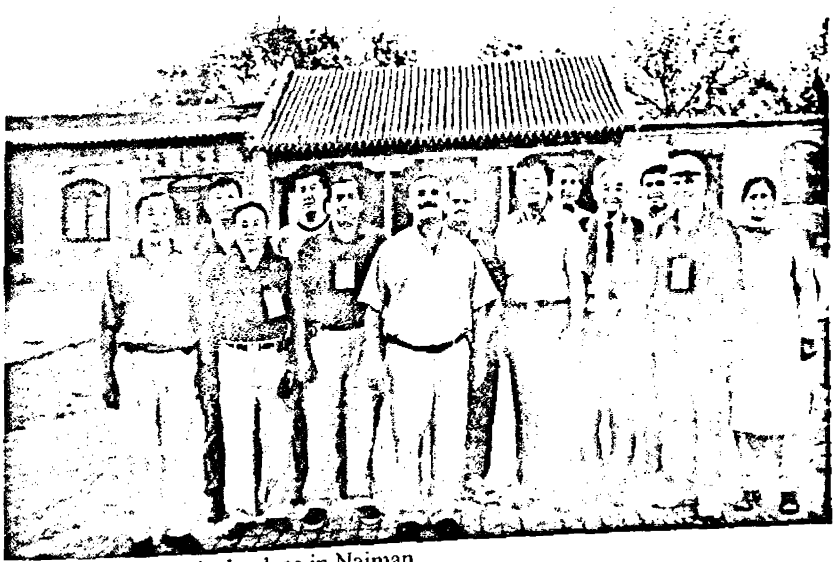
E. Visit to the Hailasu village

F. Visit to the Xinglungzhao Forest Station; afforestation in the background

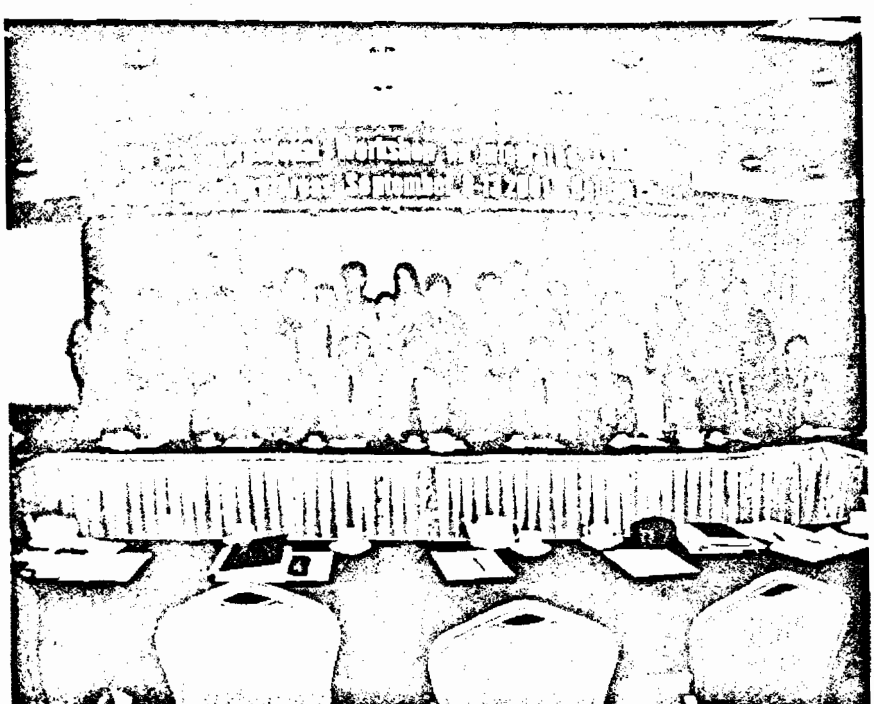


G. Visit to the Xinglungzhao Forest Station; extraction of watermelon seeds

H


H. Visit to a historical palace in Naiman

I. Workshop Plenary Session



J. Group photo of workshop participants

Workshop Programme

Friday, September 7:

Arrival of participants in Beijing

Saturday, September 8:

10:00-17:00	Cultural activity in Beijing during daytime
19:00	Leave for Naiman Field Station by train

Sunday, September 9:

08:00	Arrive at Naiman Field Station
09:00-17:00	Field activity

Monday, September 10:

9:00-17:00	Field activity and discussion
19:00	Leave for Beijing by train

Tuesday, September 11:

12:00	Arrive in Beijing
12:00-14:00	Lunch
14:00-14:30	Registration
14:30-15:30	Opening Ceremony

Technical Session 1- Overview of Soil Conservation Practices

Chaired by: Prof. Motoyuki Suzuki and Dr. Suhas Wani

15:30-16:00	The Process and Control of Desertification in Northern China (Wang Tao)
16:00-16:30	New Techniques to Combat Desertification in Tunisia (Houcine Khatteli)
16:30-17:00	An Overview of UNESCO's Activities in the Field of Dryland Conservation, Management and Rehabilitation (Thomas Schaaf)
17:00-17:30	Pioneers of Desert Studies in China and Japan (Iwao Kobori)
17:30-18:00	Discussion on Technical Session 1
18:00	**Reception**

Wednesday, September 12:

Technical Session 2 - Soil Degradation Problems and Challenges

Chaired by: Dr. Houcine Khatteli and Dr. Chen Yaning

08:30-09:00	*Desertification Prevention and Sustainable Development in* the Heihe Basin Oasis (Zhao Aifen)
09:00-09:30	A Comparison of Different Measures for Preventing Moving Sand Dunes in the Horqin Sand Land, Inner Mongolia (Zhang Tonghui)
09:30-10:00	Evaluation of Management for Combating Desertification in Horqin Sandy Land, China (Ichiro Taniyama)
10:00-10:30	**Coffee Break**
10:30-11:00	*Soil Conservation and Land Use Issues in* Uzbekistan (Muhtor Nasyrov)
11:00-11:30	*Quantitative Separation of* Anthoropogenic Effect out of the Desertification Processes (Fan Shengyue)
11:30-12:00	Relationship between Land Degradation and Sand Dust Storm Occurrence, Aeolian Sand Transport and Its Damages in East Asia During the Recent Years (Masatoshi Yoshino)
12:00-12:30	Discussion on Technical Session 2
12:30-14:00	**Lunch**

Technical Session 3 - Case Studies for Soil Conservation

Chaired by: Prof. Huang Zhiwei and Dr. Thomas Schaaf

14:00-14:30	The Effects of Revegetation on Cryptogam Biodiversity in Tengger Desert, Northern China (Li Xinrong)
14:30-15:00	Studies on the Structural Characteristics and Dynamic Change of Ecological Layer near Sandy Land Surface (Feng Jinchao)
15:00-15:30	Human Impact on Land Degradation in the Kyzylkum Desert: Ecology, Dynamics and Conservation (Kristina Toderich)
15:30-16:00	**Coffee Break**
16:00-16:20	The Strategy of Soil Conservation Farming in Tajikistan (Sanginboy Sanginov)
16:20-16:40	Improper Management of land Resourse and Land Degradation in the Horqin Sandy Land (Zhao Xueyong)
16:40-17:00	Farm Water Harvesting Reservoirs: issues of planning and management in dry areas (Theib Oweis)

17:00-17:20	Wind Velocity Profile within the Siltation Layer (Zenshin Li)
17:20-17:45	Discussion on Technical Session 3

Thursday, September 13:

Technical Session 4 - Integrated Management of Soil, Water & Natural Resources

Chaired by: Dr. Thomas Schaaf

08:30-08:50	The Response of Ecological Process after Transporting Water in break-stream Water Course of the Lower Reaches of Tarim River Basin (Chen Yaning)
08:50-09:10	Integrated Management of Water and Land in the Indus Basin (Zaigham Habib)
09:10-09:30	Conservation and Efficient Use of Natural Resources Through Integrated Watershed Management in Asia (S.P. Wani)
09:30-09:50	Chinese case study on wind erosion (Dong Zibao)
09:50-10:30	**Coffee Break**
10:30-11:00	Discussion on Technical Session 4
11:30-12:00	Development of Workshop Recommendations
12:00-12:30	**Closing Remarks**
12:30-14:00	**Lunch**

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INTEGRATED LAND MANAGEMENT IN DRY AREAS

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This workshop, jointly organized by UNU and the Chinese Academy of Sciences (CAS), focused on the issues of integrated land management, particularly soil conservation and basin-level water resource management.

The papers included in this volume provide an overview of the desertification problems and challenges in China and describe in detail the integrated land management activities undertaken. A good comparison of these activities is made in papers devoted to other regions of the world, including those focusing on Ghana, India, Jordan, Kenya, Pakistan, Tajikistan, Tunisia and Uzbekistan.

This volume also includes a set of recommendations from the workshop regarding issues related to integrating land management in dry areas.

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