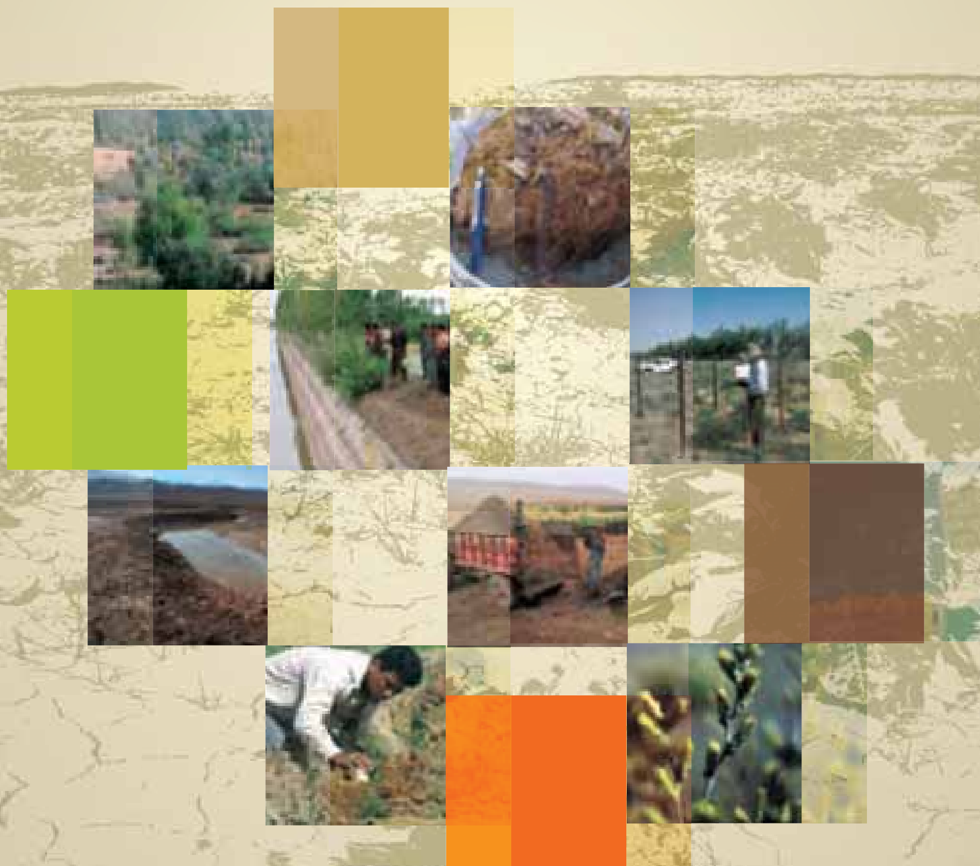
United Nations Educational, Scientific and Cultural Organization
Man and the Biosphere Programme

Sustainable Management of Marginal Drylands

Using Science to Promote Sustainable Development

SUMAMAD Project Findings from Northern Africa to Asia



United Nations Educational, Scientific and Cultural Organization
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UNITED NATIONS UNIVERSITY
UNU-INWEH
ICARDA

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Sustainable Management of **Marginal Drylands**

Institutional partners

Islamic Republic of Iran
Fars Research Center for
Agriculture & Natural Resources

Sustainable Management of Marginal Drylands

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Project Findings from Northern Africa to Asia

United Nations Educational, Scientific and
Cultural Organization (UNESCO)

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SUMAMAD

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Managing drylands – using science to promote sustainable development in Northern Africa and Asia

The world's drylands are among the most vulnerable ecosystems on our planet. Desertification and land degradation are affecting huge land areas, jeopardizing the livelihoods of millions of people. Unsustainable management practices in dryland cultivation and pastoralism have given rise to widespread soil erosion, reduction of the biological production of soils, reduction of vegetation cover, and depletion of surface and groundwater resources. In the context of global climate change, it is expected that drylands will suffer from higher frequencies and longer periods of drought, which will further threaten future improvements in human well being in these areas.

However, positive examples of managing drylands in a sustainable way exist. To put scientific knowledge at the service of improving dryland livelihood systems was the overarching aim of the Sustainable Management of Marginal Drylands (SUMAMAD) project. Drawing on the expertise of scientists and conservation experts working on the challenges imposed by drylands, this project supported dryland researchers in China, Egypt, the Islamic Republic of Iran, Jordan, Pakistan, Syria, Tunisia and Uzbekistan. It helped them to situate the problems occurring in drylands within a much wider geographical context by exchanging scientific information in an inter-regional and collaborative manner. All the study teams involved in the SUMAMAD project have brought an invaluable store of knowledge to the fore on how we can indeed manage drylands more sustainably.

After more than six years of collaborative work among study teams from very diverse countries, the results of their studies have been summarized in this publication.

The SUMAMAD project started in 2002 with an international workshop held in Alexandria, Egypt. It benefited from the scientific inputs provided by Belgian scientists from Ghent University and the Catholic University of Leuven. Just as importantly, it received substantial financial support from the Flemish Government of Belgium through a funds-in-trust agreement with UNESCO. On behalf of UNESCO, I wish to thank the people and the Flemish Government of Belgium for their confidence in entrusting the implementation of this project to UNESCO.

UNESCO's role in overseeing the project was greatly facilitated by our partner institutions, the International Centre for Agricultural Research in the Dry Areas (ICARDA), and in particular, the United Nations University (UNU) through its International Network on Water, Environment and Health (INWEH). The SUMAMAD project clearly demonstrated that inter-agency collaboration at the management level, as well as the cross-fertilization of ideas among researchers at the country and site levels, can benefit all the partners involved.

I wish to thank all the SUMAMAD project partners for the excellent work accomplished throughout this project. I am confident that the results obtained will also greatly contribute to preserving and managing our drylands for future generations.

Prof. Dr. Walter Erdelen
Assistant Director-General for Natural Sciences
UNESCO

Executive summary

The Sustainable Management of Marginal Drylands (SUMAMAD) project investigated dryland degradation and possible solutions to combat desertification in nine study sites spanning from Northern Africa to Eastern Asia. Research teams from China (with two study sites), Egypt, the Islamic Republic of Iran, Jordan, Pakistan, Syria, Tunisia and Uzbekistan, and involving the expertise of two Belgian universities, carried out in-depth studies on dryland ecosystems which were coupled with socio-economic analyses with the overall aim to improve livelihood conditions of dryland dwellers.

At the onset of the project, a baseline assessment on the environmental characteristics and the socio-economic conditions of dryland communities was conducted at each study site. This enabled the project managers to observe and measure the progress made through the selected activities implemented with the aim to improve the sustainable management of the dryland study sites. One of the main objectives of the project was to elucidate soil and water conservation techniques that could be implemented at the various project sites based on traditionally applied knowledge and enhanced by modern scientific expertise and techniques.

As the sustainable management of drylands can only yield results in the long-term by involving local dryland communities and meeting their needs for livelihood improvements, team leaders of the various project sites reached out to the communities at each study site by holding national seminars on an annual basis so that interactive feedback among the research teams, local people and government officials would lead to the formulation of practical implementation schemes aimed at sustainable dryland management.

Although the individual SUMAMAD project sites varied greatly in terms of their environmental, social, economic and political characteristics, many generic lessons and approaches for dealing with dryland challenges came to the fore. Water, or rather the lack of, is vital for any dryland development. Artificial recharge of groundwater, desalinization of saline water, water conservation schemes, and supplying quality water to people, animals and plants were successfully tested in all the project sites. Moreover, soil conservation through enhanced and diversified vegetation cover, the reduction of grazing pressure from livestock, and the rehabilitation of degraded areas through conservation measures proved to be promising intervention schemes throughout the project.

Most importantly, it was felt that the diversification of local dryland economies could be a key contribution to ensuring food security, health and economic well-being, as well as to environmental conservation at large. At each SUMAMAD project site, various new income-generating activities for local communities were tested, based on their perceived needs and aspirations. Some activities were quite novel to dryland people, such as the establishment of saline fish ponds in the Cholistan Desert, Pakistan, or chicken farming in the grasslands of Inner Mongolia, China, but they met with considerable interest and are promising initiatives for replication elsewhere. Other income-generating activities in drylands focused on promoting ecotourism, coupled with handicraft production and marketing techniques involving women cooperatives in Egypt, Jordan, Tunisia and Uzbekistan. Diversifying agricultural production, improving rangeland techniques and conserving valuable water resources as was practised by project teams in Syria, Uzbekistan and Iran testified to the innovative approaches that ensure sustainable dryland management.

The SUMAMAD project started with a scoping workshop in Egypt in 2002. Subsequent international workshops were held on an annual and rotational basis in Iran, Tunisia, Pakistan, Syria and China so that the team leaders of each sub-project could gain and exchange first-hand information and scientific knowledge on dryland management schemes as practiced in each participating country. Workshop proceedings were published and widely diffused; they can accessed on the SUMAMAD website: http://www.unesco.org/mab/ecosyst/drylands/Pub.shtml
In some cases, students were given study and practical field research opportunities at universities in Belgium and at the SUMAMAD project sites.

The project was implemented by UNESCO within the framework of the Man and the Biosphere (MAB) Programme, and in close collaboration with the United Nations University's International Network on Water, Environment and Health (UNU-INWEH), and the International Centre for Agricultural Research in the Dry Areas (ICARDA). The three partners, as well as the Chinese Academy of Sciences, contributed considerable human and financial resources to the project. The main funding for project activities was provided by the Flemish Government of Belgium through a funds-in-trust agreement with UNESCO amounting to USD 800,000 over a period of 4 years (2004–2007). Scientists from Belgian universities also provided invaluable scientific expertise to the SUMAMAD project. Thanks to additional funding by the Government of Belgium, SUMAMAD scientists were given the opportunity to present their research results at various international events related to the International Year of Deserts and Desertification in 2006, such as at the UNESCO led scientific conference 'The Future of Drylands' held in June 2006 in Tunis and the UNU-INWEH organized policy conference 'Desertification and the International Policy Imperative' held in December 2006 in Algiers.

It is hoped that the SUMAMAD project will continue through to a second phase based on discussions at the planning workshop to be held in Jordan in 2008. The findings of the SUMAMAD project should benefit researchers, local communities and decision makers worldwide so as to ensure the sustainable management of drylands today and in the future.

Description and Outputs of Field Projects

The project in context

I.A Challenges for Dryland Management

The sustainable management of drylands is vital in order to combat desertification. Desertification is a land degradation problem of major importance in the arid, semi-arid and dry sub-humid regions of the world. Deterioration of soil and plant cover has adversely affected nearly 50% of dryland areas as a result of extended droughts and the mismanagement of cultivated and rangelands. Woodcutting and overgrazing are responsible for most of the desertification of rangelands; inappropriate cultivation practices including accelerated water and wind erosion are responsible for most of the desertification in the rainfed croplands; and improper water management leading to salinization and water pollution is the cause of the deterioration of irrigated lands. In addition to vegetation loss, erosion and salinization, the effects of desertification can also be seen in soil fertility loss, soil compaction and soil crusting. Yet combating desertification by rehabilitating degraded lands can be achieved successfully using techniques already known, particularly if financial resources, scientific and traditional knowledge are made available in addition to expertise from community-based organizations and an enabling institutional environment that includes a political willingness to act.

In addition to combating desertification, it is now widely recognized that there is a need to conserve biological diversity. However, high population growth rates in most developing countries, and the associated needs to provide food and income opportunities for the growing populations using biological resources, often impede environmental conservation efforts. Arising land-use conflicts concerning protected areas, vis-à-vis the economic use of lands for agriculture, forestry, grazing, settlement, industrial and other purposes, need to be solved by providing local populations with means to manage their natural resources in a sustainable and income-generating manner. In doing so, strictly protected areas (such as national parks) cannot be dissociated from their surrounding environments, inhabited by humans who need to satisfy their immediate needs for improving their livelihoods. Biosphere Reserves under UNESCO's Man and the Biosphere (MAB) Programme go beyond the confinements of strictly protected areas and include core protected areas for biodiversity conservation, such that buffer and transition zones can embrace sustainable economic development fostered in direct collaboration with local dwellers. Various biosphere reserves were therefore selected as project study sites.

Many well-meaning innovation schemes to combat desertification and to halt land degradation have shown less than satisfactory results because they did not take into account the specific needs and/or aspirations of dryland farmers and pastoralists or their socio-cultural values, norms and traditions. While many studies in the past have focused on soil enrichment techniques, improved water retention and irrigation schemes, erosion control, sand dune fixation, and the introduction of drought-resistant xerophytes and so on, they have often done so from a purely natural sciences point of view with little, if any, consideration to the readiness of dryland dwellers to adopt new desertification control techniques. In addition, traditional knowledge on the conservation and sustainable use of natural resources has been largely overlooked or ignored as being 'non-scientific'. The World Conference on Science[1], organized by

1. World Conference on Science. 2000. *Proceedings of the World Conference on Science*. Science for the Twenty-First Century. A New Commitment, Budapest, Hungary, 26 June–1 July 1999, UNESCO, Paris.

UNESCO and the International Council for Science (ICSU), recommended that modern scientific knowledge and traditional knowledge be brought closer together when undertaking interdisciplinary projects that deal with links between culture, environment and development in such areas as the conservation of biological diversity, the management of natural resources, and the understanding of natural hazards and impact mitigation. Since land degradation is, by and large, an effect of adverse human impacts on marginal zones, it can only be remedied through inter-disciplinary scientific approaches and partnership arrangements, which understand the equal importance of inputs from scientists, decision-makers and local stakeholders. A participatory research project involving farmers and pastoralists from marginal areas and drylands, coupled with capacity-building and information management, will be essential in addressing land degradation issues. In particular, information exchange among scientists and custodians of traditional knowledge can lead to increased food security and efficient environmental and water conservation even in the world's inhospitable regions such as marginal lands.

The inter-regional Sustainable Management of Marginal Drylands (SUMAMAD) project addressed the above-mentioned challenges. Conceptualized as a project that promotes inter-disciplinary research at various field study sites in China, Egypt, Islamic Republic of Iran, Jordan, Pakistan, Syria, Tunisia and Uzbekistan it also served as a platform for the exchange of scientific knowledge among the participating countries. Learning through the shared experiences of sustainable dryland management created valuable synergistic effects which increased the knowledge base, greater than if the project had been carried out in a single study site.

In the context of the SUMAMAD project, drylands were defined as geographical regions climatologically described as arid, semi-arid or dry sub-humid. In these regions the ratio of annual precipitation to potential evapotranspiration falls within the range of 0.05 to 0.65. Drylands can be considered as all areas where the inadequate quantity and year-round distribution of precipitation fails to sustain sufficient water resources to meet the livelihood requirements of society.

'Marginal' lands were understood primarily in a socio-economic sense, where biological and economic productivity are low due to adverse climatic conditions (high precipitation variability), edaphic conditions (low organic matter in soils) and topographic terrain (slopes). Species diversity in marginal drylands is typically low, although plant and animal species have developed remarkable adaptations to severe ecological and climatic conditions such as salinity and aridity. Additionally, people living in these areas typically suffer from poverty and are vulnerable to threats related to food security.

I.B Conceptual Approach

From the purely floristic point of view, drylands are rather poor. While species diversity is much lower than in the more favoured humid zones, plant and animal species have developed remarkable adaptations to severe ecological and climatic conditions such as high salinity and pronounced aridity. In a similar manner, humans have developed traditional systems of territorial planning and management in order to benefit as much as possible from the diversity of the available resources.

This merits special attention, in particular for the maintenance, sustainable management and enhancement of gene-pools and natural resources present under adverse conditions. From a conservation point of view however many species in dryland Africa and Asia are seriously threatened. Owing to the mismanagement and overexploitation (overgrazing, burning, over-cutting of wood species, exploitation of medicinal herbs and plants, ploughing of the steppes for agriculture, over-pumping of groundwater and so on) many plant species are now on the verge of extinction. Traditional crop species and wild relatives of crops are also under threat due to the introduction of high yielding cultivars. Regarding wildlife, most of the large mammals and game species are on the verge of extinction due to the modification of their natural habitat and food supply as well as recent over-hunting. Due to the harsh environment, combined with erratic rainfall, it is most likely that the drylands will have to rely on their own genetic resources if long-term sustainable development is to be sought. The rehabilitation of degraded drylands therefore becomes a necessity.

The availability of quality freshwater resources is a decisive factor in dryland ecosystems and human livelihood systems. Due to the pronounced climatic variability in the drylands, with their extremely varying temporal and spatial precipitation patterns, the conservation and sustainable use of freshwater resources is crucial for the continuation of human, plant and animal life. The rational use of freshwater resources, based upon both traditional technologies and scientific knowledge, needs to be addressed in an encompassing manner that does not dissociate water from its dryland ecosystem. Moreover, the interrelationships of freshwater, used water, sanitation and human health are particularly important in drylands and are vital to sustainable development. The provision of healthy living conditions for flora, fauna and humans in the light of adequate water supply and water quality cannot be underestimated when considering the sustainable management of marginal drylands.

Drylands in Northern Africa and Asia show many similar characteristics, for example in terms of variability in seasonal precipitation, pronounced diurnal temperature differences, poor soils with low organic matter and mineral content, fragile vegetation cover and vulnerability to erosion, which make them interesting from a comparative point of view. However, they also show marked differences in their cultivation patterns as well as their socio-economic and political parameters that determine land-use and land management, as observed within the UNU-drylands network.

Human beings have inhabited drylands for millennia. In the course of human evolution, management schemes have been developed that are based on 'experiential' knowledge rather than on knowledge based on tested experiments. The combination of modern scientific expertise with traditional knowledge systems can potentially support sustainable livelihoods in areas with few natural resources.

With these considerations in mind, the SUMAMAD project addressed various objectives expected to lead to the following results:

- Improved and alternative livelihoods of dryland dwellers.
- Reduced vulnerability to land degradation in marginal lands through efforts to rehabilitate the degraded lands.
- Improved productivity through identification of wise practices using both traditional knowledge and scientific expertise.

At the operational level, the SUMAMAD project aimed at reaching inter-related objectives that would enhance the sustainable management of marginal drylands:

- To facilitate the sustainable and integrated management of marginal drylands and their natural resources including land, water and biodiversity resources in collaboration with dryland-users.
- To investigate alternatives and non-conventional sources of water and encourage their use to better match the water demand and supply in these water scarce zones.
- To promote healthy living conditions by analysing

the supply and quality of freshwater resources in the context of sanitation and human health.

- To help scientists and conservation experts working in the targeted region in strengthening the conservation of their natural resources and environmental protection through the rehabilitation of the degraded marginal lands as well as increased knowledge sharing.
- To support on-going scientific capacity-building programmes, with emphasis on south-south collaboration for the transfer of environmentally-sound technology and expertise, including the incorporation and development of traditional knowledge.
- To disseminate scientific findings through publications diffused globally among the networks of UNESCO, UNU and ICARDA, thus ensuring a transfer of knowledge to other arid and semi-arid regions in developing countries.
- To reach out to dryland populations by way of national workshops, which involve local stakeholders, government officials and scientists.

In this vein, the project adopted a systematic approach for the long-term *in situ* conservation of natural resources by involving and supporting local populations in their efforts to use their natural resources in a sustainable manner, and through the application of scientific methods for the improved management of marginal drylands. To evaluate the effectiveness of existing practices, a common assessment methodology was worked out by the project's core management group, and was set as the initial task for all the project sites at the start of the SUMAMAD project.

This assessment methodology was applied to all the project study sites to ensure a certain degree of uniformity throughout the project for comparative purposes. The assessment methodology comprised information gathering and evaluation for the following three elements:

a. state of existing natural resources;
b. characterization of stresses; and
c. description of indigenous, adaptive and innovative approaches.

a. State of Existing Natural Resources – water, soil, biodiversity

As it was important to fully understand the state of existing natural resources at the local level, and their mutual relationships at other geographic scales (e.g. basin-wide, national or regional), a certain level of integration between the conservation of natural resources, community development and scientific research was deemed essential and was thus elaborated for each study site.

With regard to water resources, both surface water and groundwater resources were evaluated for their capacity and long-term sustainability. The spatio-temporal characterization of precipitation and hydrometric data were compiled (e.g. averages, variation, intensity, return periods, runoff coefficients, hydrographs). Similarly, hydrogeologic maps describing the aquifer systems as well as the quality criteria (pollutants, salinity levels) were also consulted. With regard to soils, localized maps of soil characterization and land-use patterns were used. This information allowed a preliminary assessment for the risk of land degradation for each geomorphologic zone of the region as well as their production potential. With regard to biodiversity resources, a compilation of information was made for the major vegetation units, biomass quantification and species richness in the respective study sites.

b. Characterization of Stresses

An overall characterization of the typical environmental stresses was undertaken, which included population growth, urbanization dynamics, industrial activities and reliance on agriculture. A number of socio-economic factors like poverty levels, per capita income, access to public health and education facilities, and existing livelihood options were assessed for the project study sites. It was also important to characterize the consumption patterns among the local communities as well as their interdependence on livelihood generating activities.

c. Description of Indigenous, Adaptive and Innovative Approaches

The purpose of this element was to determine how local communities have adapted to conditions in the marginal drylands and whether such adaptations are sustainable in the long-term. For this purpose a compilation of various management approaches and technologies – indigenous, adaptive and innovative – were made, including water resource management practices. It was also important to consider the role of government in the development, application and implementation of these approaches. One key factor is the land tenure system, which is often central to the natural resource management paradigm. Yet other factors include the availability of alternative livelihoods and the capacity of communities to adopt them. Needless to mention, awareness-raising and capacity-building is often required for such approaches to succeed in the long-term. Such descriptions are extremely useful in sharing information across national and continental boundaries, perhaps leading to cross-fertilization of ideas and innovative approaches.

For the study sites to be affiliated with the SUMAMAD project, several of the following basic criteria had to be met:

- The study site should be representative of marginal lands as defined in this project as well as the wider region of the country under study such that it functions as a testing and demonstration site, and should include major types of land degradation and communities affected by such processes.
- The activities at the study site must demonstrate the integration of disciplines and approaches.
- The group undertaking the work should be interdisciplinary in its composition, and should involve experts of traditional technologies, and possibly NGOs.
- The scientists in the group must be recognized in their respective field for the quality of their research work;
- There should be clear prospects for the continuity and sustainability of the sub-project itself, in particular with regard to the income-generating activities.
- There should be clear mechanisms for the transfer of knowledge to other similar activities in the other partner countries.
- The research work must include explicit mechanisms for the exchange of expertise between custodians of traditional knowledge, scientists and local communities.

For the most part, the project relied on existing activities within institutional networks such as UNESCO's Man and the Biosphere (MAB) Programme and the World Network of Biosphere Reserves and the International Hydrological Programme, (IHP), and research institutions associated with the United Nations University International Network on Water, Environment and Health (UNU-INWEH), and the International Centre for Agricultural Research in the Dry Areas (ICARDA) network of field stations and integrated research sites in the West Asia and North Africa (WANA) region; thereby avoiding an *ad hoc* approach. The SUMAMAD project aimed *inter alia* at creating a coordinated network of study sites linked by a common understanding of purpose, which would provide benefits to each participating site in a synergistic manner.

The collaboration of the three complementary partner institutions making up the project's core management group – UNESCO, UNU-INWEH and ICARDA – also lead to global outreach and methodological advances in comprehensive dryland research, management and conservation, which benefited other dryland regions not covered by the project. In particular, thanks to additional financial support provided by the Flemish Government of

Belgium, the SUMAMAD project findings were presented at two major international events held in the framework of the International Year of Deserts and Desertification in 2006, and thus allowed the SUMAMAD project team leaders to share their project results with other dryland experts from the world over. The two events were:

- the International Scientific Conference on 'The Future of Drylands' organized by UNESCO and other partners including UNU and held in Tunis (Tunisia) from 19 to 21 June 2006; and
- the International Conference on 'Desertification and the International Policy Imperative', organized by UNU and other partners including UNESCO and held in Algiers (Algeria) from 17 to 19 December 2006.

In terms of specific project activities, SUMAMAD project partners received financial support from the SUMAMAD project budget to strengthen their research capacities on activities pertaining to sustainable dryland management and the rehabilitation of degraded areas. Closely following the SUMAMAD Project Document, with only slight modifications, the project partners worked according to a phased workplan and timeline as outlined below:

a) A comprehensive assessment methodology for integrated natural resource management was developed by the core management group (start of the project).
b) For each study site, an assessment was made of the current status of integration between the conservation of natural resources, community development and scientific information as well as the mechanisms for management and co-operation, all of which can then feed into an overall dryland management concept. This assessment included socio-economic surveys aimed at identifying and understanding people's adaptation to management approaches, at evaluating strategies adopted by dryland stakeholders, and at identifying dryland management approaches that promote sustainability, based on a balance between human needs and resource conservation (Year 1).
c) Practices for sustainable soil and water conservation were identified with the local communities, and were promoted via a site-specific approach. Practices involving traditional knowledge as well as modern expertise, or a combination thereof, were tested with a view to combating environmental degradation, increasing dryland agricultural productivity, and enhancing resource conservation (Year 2 to Year 5).
d) Associated training on the handling of data collection and inventory techniques as well as on proven management technologies were offered at the annual international project workshops (Year 1 to Year 4).
e) At each site, one to two income-generating activities, based on the sustainable use of dryland natural resources, were explored and supported within the financial means of the project (Year 1 to Year 4).
f) National group training programmes on dryland conservation issues, land management, rehabilitation of degraded areas, and the rational and sustainable use of natural resources, using both traditional knowledge and modern science were organized at each study site on an annual basis, and were targeted specifically at local populations at the grass-roots level as well as to scientists (Year 1 to Year 4).
g) Annual international workshops including project steering committee meetings, comprising 1 to 2 researchers and the biosphere reserve managers of each study site were held jointly as a means to harmonize approaches, to link up procedures, to exchange information and experience, and if needed, to adjust workplans (Year 1 to Year 4).
h) The project results were published in English and are to be widely distributed by UNESCO, UNU and ICARDA, in order to achieve multiplier effects (Year 4).

I.C Quality Criteria for Selection of Study Sites

The study sites affiliated with the overall project had to meet some of the following basic criteria:

- The site should be representative of marginal lands as defined in this project as well as of the wider region of the country concerned so as to function as a testing and demonstration site, and should include major types of land degradation and communities affected by such processes;
- The activities at the study site must demonstrate the integration of disciplines and approaches;
- The group undertaking the work should be interdisciplinary in its composition, and should involve experts of traditional technologies, and possibly NGOs;
- The scientists in the group must be recognized in their respective field for the quality of their research work;
- There should be clear prospects for the continuity and sustainability of the sub-project itself, in particular with regard to the income-generating activities;
- There should be clear mechanisms for the transfer of knowledge to other, similar activities in other countries;
- The research work must include explicit mechanisms for the exchange of expertise between custodians of traditional knowledge, scientists and local communities.

I.D Overview of Study Sites

China

a) **Heihe River Basin (HRH)**: The Heihe river originates from Qilian Mountain; precipitation in mountains and melting glaciers are the main water sources. It is the largest river inland of the Hexi area (ca. 820 km in length) and flows through Qilian county of Qinghai province, the Hexi corridor of Gansu province, and Ejina Qi of Inner Mongolia Autonomous region. There are almost 200 million people living in the river basin. According to the survey data of the 1980s and 1990s, the net utilization rate of the river water was 48.96% and 57.4% respectively, well over the estimated safe rate of 40%. Towards the end of the twentieth century, the lakes and river branches disappeared in the lower reaches of the river. In recent years, the over-exploitation and expansion of the oasis, its flood irrigation and increased population have caused more frequent breaks in the river flow. Essentially, the conflict lies in the allocation of water between upstream and downstream users as well as in economical development and ecological security. Water resources are limited in the arid area; more water is consumed at the upper reaches of the river resulting in shrinking and drying out of the downstream oases. Accordingly, the mountain, the oases and the desert are linked by the river as one eco-functional system.

b) **Hunshandake Sandland (HS)**: Located in the middle of Xilingol Plateau, Inner Mongolia, and close to the Xilin Gol Biosphere Reserve, Hunshandake is one of the ten major sandland areas in China. It is well-known as a source of the dust storms that blow in from the north towards Beijing and Tianjin. Project activities include environmental monitoring, sand dune fixation, natural regrowth of grasslands, the creation of employment opportunities aimed at minimizing environmental degradation, and the creation of protected areas, all in an integrated and holistic framework (such as the biosphere reserve concept).

Egypt

The Omayed Biosphere Reserve (OBR) is located in a warm desert and semi-desert ecosystem with coastal calcareous dunes consisting of: *Ammophila arenaria, Euphorbia paralias, Pancratium maritimum* etc.; inland ridges with skeletal shallow soils characterized by either *Thymellaea* spp. and *Gymnocarpus decadrum* communities or by associations of *Plantago albicans* and *Asphodelus microcarpa*; saline marshy depressions dominated by

Salicornia fruticosa, Cressa cretica, Atriplex halimus etc; non-saline depressions and inland plateau including species such as *Artemisia monosperma* and *Hammada elegans* associations (calcareous soils), *Anabasis articulata* and *Hammada scorpia* (shallow degraded soils) and *Suaeda pruinosa* and *Salsola tetrandra* communities (saline soils); pasture land, and fig plantations. Covering a total area of 75,800 ha and ranging in altitude from 0 to +110m, the site was designated as a biosphere reserve in 1981 and extended in 1998. The project focused on a wide variety of activities, including ecosystem studies, employment generation opportunities for local communities, and the establishment of solar-powered desalinization plants to provide safe drinking water.

Islamic Republic of Iran

The undulating area south-west of the **Gareh Bygone Plain (GBP)** is a submarginal rangeland-used by nomad farmers. In the wake of recurring droughts and declining freshwater resources, food security has become an important challenge. While floodwaters occur frequently, no efforts have been made to manage or retain them for future usage. By applying floodwater spreading for the artificial recharge of groundwater and by optimising water-use efficiency, the number of livestock, and the area used for irrigation agriculture, could be increased.

Jordan

The Dana Biosphere Reserve (DBR) is located in a warm desert and semi-desert ecosystem with Mediterranean semi-arid forest with oak (*Quercus calliprinos*), juniper (*Juniperus phoenicia*), cyprus (*Cupressus semperivirens*) and wild pistachio (*Pistachio atlantica*); mid-altitude steppe with shrubs such as *Artemisia herba-alba, Retama raetum* and *Anabasis articulata*; *Acacia* sub-tropical habitats with *Acacia* spp., *Ziziphus spina-christi* and *Ficus* spp.; sand-dune desert with *Acacia* spp. and *Haloxylon persivum*. Covering an area of 30,800ha and ranging in altitude from +100 to +1,500m, the site was designated as a biosphere reserve in 1998. Project activities focused on elaborating integrated management schemes for this dryland area, as well as income-generation activities.

Pakistan

Lal Suhanra Biosphere Reserve (D/LSBR) is located in a warm desert and semi-desert ecosystem including sub-tropical thorn forest with *Calligonum polygonoides, Calotropis procera, Capparis decidua, Prosopis cineraria, Tamarix aphylla* etc.; lesser Cholistan desert is characterized by *Crotalaria burhia, Zizyphus mauritania, Haloxylon recuryum, Aerva javanica* etc.; irrigated plantations with *Acacia nilotica, Dalbergia sisson, Eucalyptus camaldulensis, Prosopis cineraria, Tamarix aphylla, Capparis decidua, Salvadora oleoides*; freshwater wetlands including species such as *Eichornia crassipest, Hydrilla verticillata, Neltumbo nucifera, Nymphaea lotus, Phragmites karka* and *Typha dominagensis*. Covering a total are of 65,791 ha, the site was internationally recognized as a biosphere reserve in 1977. In the adjacent Cholistan desert and research sites, project activities included soil and water conservation, and the establishment of saline fish ponds to diversify income opportunities for dryland communities.

Syria

The Khanasser Valley (KVIRS) is a typical dryland area in the transitional rainfed agriculture – rangeland zone of Syria. The valley is located approximately 70 km southeast of the city of Aleppo. The area falls within the winter rainfall zone of 200–250 mm per year and is therefore marginal for cereal production. Rainfed barley is the dominant field crop. In the valley floor, the soils are deep and have the potential to retain a lot of moisture. Whenever water for irrigation is available, farmers grow wheat and occasionally vegetables in summer. Over the past 15 years, farmers have dug many irrigation wells to supplement the rainfall and grow fully-irrigated summer crops. Over-exploitation of the groundwater is a major concern. Approximately 11,000 people live in 26 villages; another 32 villages are located in the surrounding hill ranges and rangelands. The people are impoverished and out-migration to work as seasonal laborers is common. Seasonal in-migration of Bedouin flocks in the summer may bring in another 25,000 animals that graze on cereal stubble and other crop residues resulting in serious overgrazing of the grazing areas and soil damage on harvested fields due to excessive trampling. The relatively high densities of human and livestock populations in the valley put enormous pressure on the land resources of the area and soil degradation is serious. On the overgrazed and denuded valley slopes, the soil resources are limited. Under current land-use practices, the productivity of these stony slopes is low. However, with appropriate soil and moisture conservation measures and nutrient management, there is considerable potential for tree and shrub plantations. Research focused on diversifying pastoralism and crop production.

Tunisia

In the **Zeuss-Koutine watershed (ZKW)** of south-eastern Tunisia, which is characterized by steppe vegetation in an arid climate and situated at the edge of the Jebel Matmata and Jeffara geological landscape, anthropogenic pressure has increased considerably since the 1960s leading to environmental degradation in terms of reduced vegetation cover, poor and eroded soils, overgrazed rangelands and increased competition for access to water resources. Adaptation mechanisms of the local population to environmental change were analysed in the context of the project, and assessments and validations of techniques for combating land degradation were carried out including incentives to establish an ecotourism scheme in collaboration with local NGOs.

Uzbekistan

Karnab Chul (KC) is a steppe region located in the southern part of Uzbekistan south of the Kyzylkum Desert. Agriculture is practiced on 62% of the country's 44.5 million hectares, with irrigated land occupying only 15% of farmlands. Intensive irrigated farming in the past, particularly of cotton, and the lack of any system of crop rotation has resulted in widespread degradation of the natural resources, with accompanying losses of organic matter and soil fertility, and increased salinity. About half of the land area is rangeland and overgrazing has destroyed many plant communities, especially those close to watering points. Research focused on adequate pastoral management schemes and the development of ecotourism and handicraft production to diversify dryland economy.

I.E International SUMAMAD Workshops

The exchange of knowledge and expertise on applied dryland management among project participants was a key element in the SUMAMAD project. In addition to annual national seminars at each project site, a number of international workshops were organized on a rotational basis in the various project countries so that the SUMAMAD partners could gain insight into the field activities carried out by each research team. These workshops also served to review project accomplishments over the preceding year and to agree on project activities for the following year. The following text provides a brief summary of the international workshops and also informs on various meetings held by the project's core management group that marked the launch of the SUMAMAD project.

Following the preparation of a draft SUMAMAD Project Outline by UNESCO and UNU in late 2001, representatives of the UNESCO-MAB Programme, UNU and ICARDA met at UNESCO Headquarters in Paris in May 2002 to discuss the selection of scientific institutions and project sites from their various international networks, which would constitute the participating partner countries.

Representatives of the SUMAMAD partner institutions and project sites later met for the first time at what is now considered the First International Project Workshop on 'Sustainable Management of Marginal Drylands – Application of Indigenous Knowledge for Coastal Drylands' in Cairo and Alexandria (Egypt) from 21 to 25 September 2002. Primarily organized by UNU, the workshop was also attended by Belgian scientists from Ghent University and the Catholic University of Leuven, who made an assessment of the project for funding by the Flemish Government of Belgium. At a field trip, the workshop participants had the opportunity of seeing natural vegetation regrowth dynamics at Omayed Biosphere Reserve. The workshop proceedings were published by UNU in 2003 as Volume No. 5 of the UNU Desertification Series.[2]

UNESCO, UNU and ICARDA representatives met again at the occasion of the Third World Water Forum in Kyoto (Japan) in February 2003 to work out a plan in order to keep the project momentum going until larger-scale financial support was secured by the Flemish Government of Belgium. It was decided that UNU provide grants to the SUMAMAD project countries in 2003 to elaborate site-specific assessments with a view to reaching the first project objective. Moreover, UNESCO funded and organized the following international SUMAMAD project workshop in Iran later that year.

The Second International Project Workshop concerned the overall theme of sustainable management of marginal drylands and was held in Shiraz (Iran) from 29 November to 2 December 2003 with the participation of all the project partners. It was hosted by the Fars Research Centre for Agriculture and Natural Resources (FRCANR). The team leaders of the sub-projects presented the results of their site-specific environmental and socio-economic assessments. During a field trip, workshop participants were informed about FRACNR's activities in artificial groundwater recharge in the Gareh Bygone Plain. The workshop proceedings were published by UNESCO in 2004 as Volume No. 3 of the UNESCO-MAB Drylands Series. It is also available in PDF format:http://unesdoc.unesco.org/images/0013/001354/135470e.pdf

The team leader of the Tunisian sub-project at the *Institut des Régions Arides* took on the task of organizing the Third International Project Workshop in Djerba (Tunisia) from 11 to 15 December 2004 in collaboration with UNESCO. The field visit to the Zeuss-Koutine watershed area served to demonstrate groundwater recharge measures and monitoring as well as examples of alternative income opportunities for dryland dwellers such as ecotourism. The workshop proceedings were published by UNESCO in October 2005 and are available in PDF format at http://unesdoc.unesco.org/images/0014/001424/142426E.pdf

Originally scheduled for November 2005, the Fourth International Project Workshop was postponed following the devastating earthquake that affected Pakistan in October 2005. Consequently, the Fourth International Project Workshop was held in Islamabad (Pakistan) from 27 to 31 January 2006 and was hosted by the Pakistan Council of Research in Water Resources (PCRWR). The workshop also included a field trip to Lal Suhanra Biosphere Reserve and the Cholistan desert where PCRWR is operating several saline/brackish water fish ponds as an income-generating activity for the dryland communities. The workshop proceedings were published by PCRWR and are available in PDF format at http://unesdoc.unesco.org/images/0014/001473/147306E.pdf

ICARDA hosted the Fifth International Project Workshop at its Headquarters in Aleppo (Syria) from 13 to 16 November 2006. Apart from reviewing project accomplishments over the preceding year at each project site, this workshop also served to critically assess the overall project by SWOT analysis. Moreover, using a logical

2. Adeel, Z., ed., (2003). *Sustainable Management in Marginal Drylands - Application of Indigenous Knowledge for Coastal Drylands*, UNU Desertification Series No. 5, UNU, Tokyo, Japan.

framework matrix, SUMAMAD partners outlined the project objectives for a second project phase should the Flemish Government of Belgium and/or other donors provide project funding beyond the end of the current project phase. The field visit to Khanasser Valley served to visit various ICARDA project activities, such as the rehabilitation of an ancient qanat, and a nursery for dryland crops and fodder plants. The workshop proceedings were published by UNESCO in 2007 and are available in PDF format at http://unesdoc.unesco.org/images/0015/001531/153198E.pdf

The Sixth International Project Workshop was held in Xilinhot City and Zenglan Banner (China) from 6 to 12 September 2007 and was hosted by Prof. Jiang Gaoming of the Chinese Academy of Sciences. The SUMAMAD team leaders presented the overall results of their project activities since the start of the SUMAMAD. A field trip was organized to Xilingol Biosphere Reserve and to the Hunshandake Sandland area, where the rehabilitation of grasslands through natural regrowth is tested and monitored. At this workshop it was agreed that no workshop proceedings will emanate from this event as this final SUMAMAD publication will summarize the project results obtained throughout the entire project period (see the following chapters for descriptions and outputs of the nine field projects).

The Jordanian team leader offered to host the Seventh International Project Workshop in Dana Biosphere Reserve in June 2008. This workshop will primarily be a planning workshop to finalize the project document for the second phase of the SUMAMAD project to possibly begin in early 2009.

1 Hunshandake Sandland

China

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1. Main dryland challenges at the project site

Severe sandland and grassland degradation has been occurring in China over several decades leading to serious yellow storms, or snow sandy storms (Yoshino, 2001; SEPA, 2002). In Beijing, yellow storms occurred twelve times in 2000, and eighteen times in 2001. Such storms used to occur once in thirty years, such as during the 1900–1930s. Even during the 1960–1970s, only one yellow storm every two years was recorded (Jiang, 2002). Hunshandake Sandland, Inner Mongolia in northern China, is well-known as a source of sandstorms, which blow in from the north in a southerly direction threatening the Beijing and Tianjin areas. By 2000, some 80% of the grasslands in Hunshandake Sandland had deteriorated into sandy or desertified lands (Li *et al*, 2001), and 33% of land was comprised of mobile sand dunes – up from less than 2% in the 1960s. Therefore, the severe problem of yellow storms is mostly attributed to the degradation of the vast grassland in Inner Mongolia, especially in Hunshadake Sandland as it is the nearest great sandland to Beijing.

Grazing has far exceeded the carrying capacity of vast areas of grassland in China, particularly in the North and Northwest, producing degraded land that is vulnerable to wind and water erosion. Chinese desert control projects have been going on for half a century but the results were disappointing with large tracts of grassland continually degrading. It was suggested that there was a misunderstanding about the best course for desert control. Officials and the public often assumed that tree planting should be the first choice for action (French, 2004). However, arid weather in these sandy areas could not provide enough water for the trees (Huang, 1982) and providing irrigation for trees planted on uneven land was inefficient and costly.

So, it was necessary to find a new approach towards the restoration of degraded grassland while sustaining the local communities. With financial support from SUMAMAD, we conducted this project to try and meet the above-mentioned targets. The study was carried in Hunshandake Sandland, Inner Mongolia, based on the idea that if the human and animal pressure was reduced, natural processes would be encouraged to take place. The concept of biosphere reserves, which combines the achievement of scientific findings and social development, was fully considered in our project. The importance of establishing a biosphere reserve was also clearly recognized by the local government of Zhenlan Banner (Banner means county in the Mongolian language), Inner Mongolia, where Hunshandake Sandland is principally situated.

2. Environmental characteristics of the study site

Located in the middle of Xilingol Plateau, Inner Mongolia, Hunshandake Sandland (41°56′-44°22′N, 112°22′-117°57′E, 1100-1300 m a.s.l.) is one of four major sandlands in China (the other three are Kerqin, Maowusu and Hulun Beier) (Figure 1). Hunshandake Sandland starts from the east Dali Lake, through the Southwest Great Xing'an Mountain, and extends westerly to Jining-Erlian. It is about 450 km in length and 50–300 km wide with a total area of 53,000 km^2.

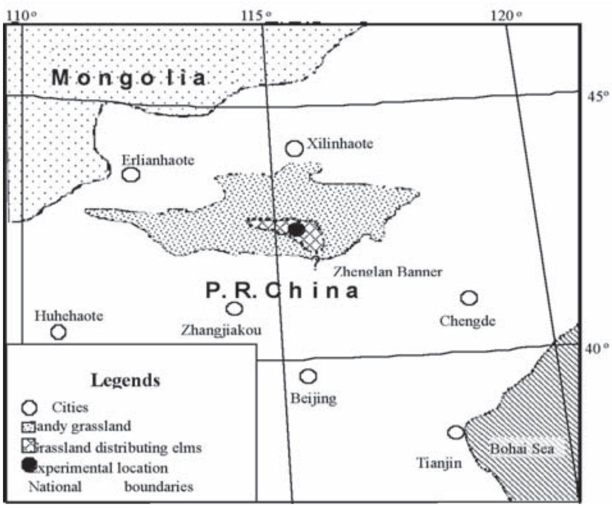

Figure 1 : The location of the study area and experiment site in Hunshandak Sandland, Inner Mongolia, North China.

It is situated in one of the sandiest and windiest areas in China with an average wind speed of 3.5–5.5 m/s, and a maximum of 24–28 m/s; and 60~80 days per year with wind velocity reaching 19 m/s. Hunshandake Sandland is controlled by temperate semi-arid climate with a mean annual temperature of 0.5–3.5 °C; mean annual precipitation between 250–400 mm; and mean annual potential evaporation of 2,000–2,700 mm. More than 50% of the annual rainfall is concentrated in July and August when the monthly (July) mean peak temperature 17 ° C also occurs. Although the average air temperature shows little change over the years (Figure 2A), effective accumulate temperature (Figure 2B), average annual precipitation (Figure 3A) and hours of sunshine (Figure 3B) fluctuate within years, which may partly explain the vegetation dynamics and the occurrence of yellow storms.

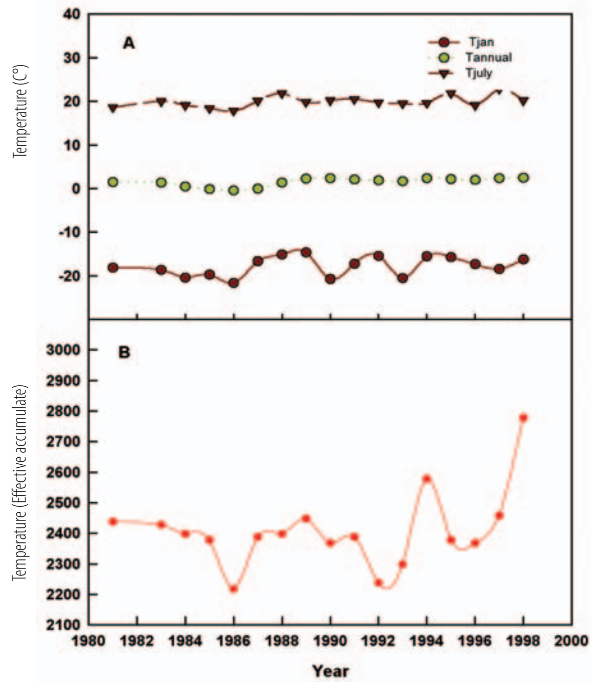

Figure 2 : The average temperature (A) and effective accumulate temperature (B) during the past 20 years.
(Source: Zhenglan Banner Weather Sate Monitored Data)

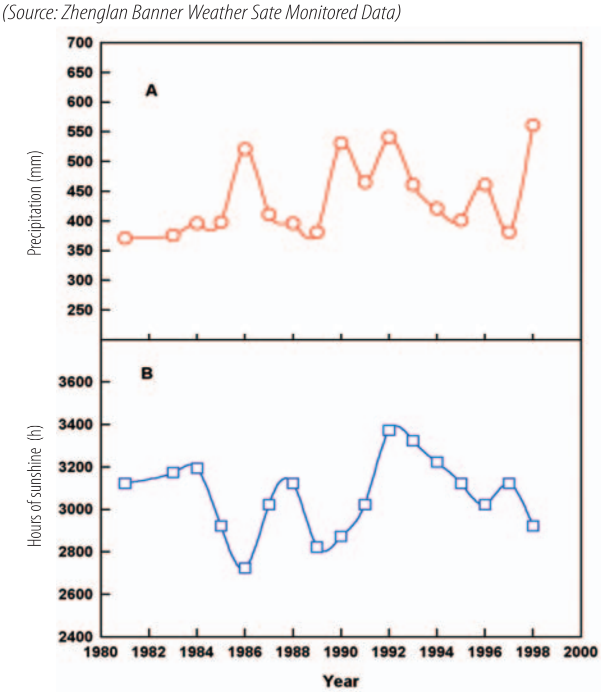

Figure 3 : The average precipitation (A) hours of sunshine (B) in Hunshandake Sandland during the past 20 years.
(Source: Zhenglan Banner Weather Sation Monitored Data)

The entire sandland consists of five main habitats: fixed dunes, semi-fixed dunes, shifting dunes, lowland, and wetland. The main soil type is chestnut aeolian sandy soil. Siberian elm (*Ulmus pumila*), the most important dominant tree species, grows sparsely and unevenly in the sandland and thus forms the sparse forest grassland landscape composed of a dense herbaceous layer, with some shrubs and sparse trees distributed in the grassland surroundings.

The woody components of the vegetation are dominated by *Ulmus pumila* (native species), *Salix gordejevii, Malus baccata, Ribes pulchellum*, etc. In the lowland and wetland, the vegetation is dominated by grasses such as *Corispermum heptapotamicum, Salsola collina, Leymus chinensis, Digitaria ischaemum, Orostachys malacophyllus, Allium mongolicum,* and *Campanula rotumdifolia*. Some 800 higher plant species, more than 402 vertebrate species, 174 birds and 526 insects have been recorded, with the total number of species exceeding 1,500 (Zhenglan Banner Government, 2001). Six rare or threatened species listed by the IUCN have also been reported.

3. Socio-economic characteristics of the study site

With a population of 128,000 Hunshandake Sandland is located in an area of pure pasture with 92% of its income obtained from livestock breeding. Among the different animals, cattle occupy 24%, goats 35%, and sheep, horses and camels together occupy the remaining 41%. As the largest Banner in Hunshandake Sandland, Zhenglan Banner has a population of 73,000; 40 % of whom are Mongolian, which is greater than the average of Inner Mongolia (12%). The rapid increase in animals occurred during the 1990s with the highest recorded number of 108,000 animals being raised in 1990 (Figure 4A). The rapid increase in small animals, especially goats and sheep (800,000), ranks as one of the main reasons for the severe degradation of the sandland.

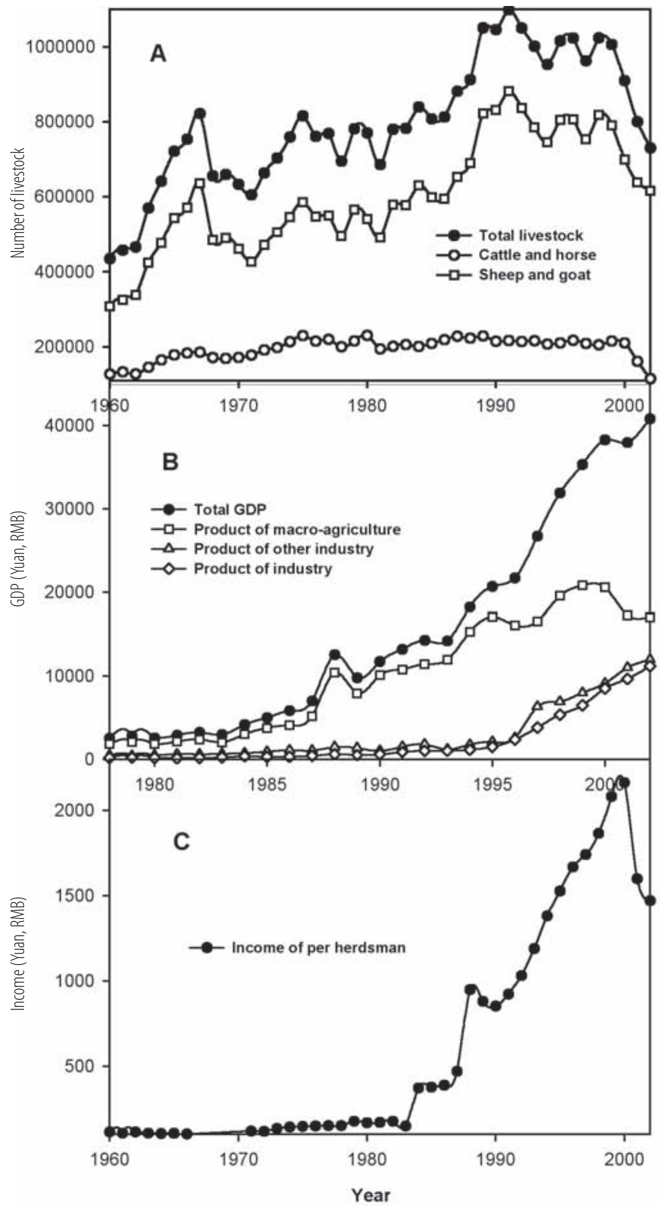

Figure 4 : Changes in the number of livestock (A) and its formation, GDP (gross domestic product) and its structure (B), and average income of per herdsman (C) in Zhenglan Banner of Hunshandake Sandland during 1960-2002. 1 USD=8.3 RMB before 2004.

The banner had a financial income of USD 21 million in 2002 (1 USD is equal to approximately 8.3 RMB, at the end of 2004) (Figure 4B). The average income of one herdsman during 1960–1990 was less than 1,000 RMB per year (Figure 4C), when the whole country was lesser developed. Financial income has changed over the last 50 years. For example, the ratio of income from livestock production to GDP has shrunk whilst income from industry and other activities has grown. Some parts of traditional herding/breeding would be gradually replaced by modern herding/breeding methods (restricted grazing, breed selection, etc.) and related agri-business and other industries.

There are three small towns situated in the moderately and least desertified grassland in Shangduyin Gol, Sanggandalai and Habiriga, where rural residents have expressed a willingness to leave (Figure 5). These three towns cover an area of 10.2 km^2 (0.1%. of the Zhenglan Banner's total area), but now contain 32% of the banner's total population, and still will have large potential for welcoming more people.

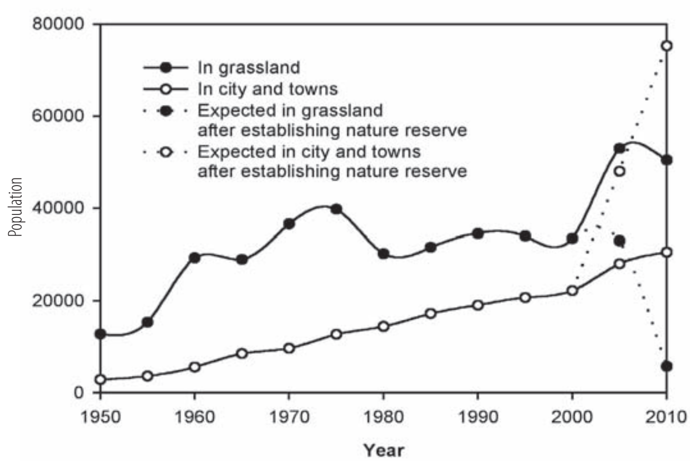

Figure 5 : Changes of population in cities (towns) and in grassland during 1950-2000, expected trend during 2005-2010, and expected population after the establishment of a nature reserve in Zhenglan Banner of Hunshandake Sandland.

The population in towns has been increasing at the rate of 1–1.9% per year since the 1950s. Most of these people come from pasture areas. A plan, using natural processes to recover the degraded grassland, was proposed by scientists from the Chinese Academy of Sciences and accepted by Zhenglan Banner; the population increase of towns was therefore expected. Figure 5 shows the changes of population in cities (towns) and in grasslands during 1950–2000; the expected trend during 2005–2010 and the expected population after the establishment of a biosphere reserve in Zhenglan Banner. Moving the population from the pastures into towns would satisfy the human resource needs required in the future because of the economic development of towns and cities. At present, there are more than 10 major projects under construction or planned in Shangduyin Gol that include tourism, livestock processing, real estate and other industrial developments; the total projected investment is 21,000 million RMB. The project area will host a population of 20,700 in 2002 and 51,200 in 2010, including employees.

4. Conservation of natural resources, community development and scientific information

4.1 Determining land degradation

Land desertification was estimated by combining remote sensing data (Landsat TM image) with GIS and statistical data from the Grassland Administration of Zhenglan Banner, and confirmed through field surveys. Rangeland was classified into 4 landforms: sparse-elm-forest, lowland, hills, and wetland. The method of Chen and others (2002) was used to determine the degrees of desertification. The desertified grassland was classified into three categories integrating both ecosystem and herbage quality for animals. The ratios of plant community height to the

Landform	Desertification area (km^2)	Severe desertification area (km^2)	Population in severe desertification area
Sparse-elm-forest	4,582 (45%)	2,138 (21%)	4,121
Lowland	3,258 (32%)	1,629 (16%)	2,237
Hills	1,222 (12%)	407 (4%)	3,526
Wetland	1,018 (10%)	305 (3%)	623
Total	**10,080 (99%)**	**4,480 (44%)**	**10,507 (13%)**

Table 1. Area (km^2) of desertification grassland and human population in four landforms of Zhenglan Banner, Hunshandak Sandland. Percentage to total area is given in brackets.

potential plant height (without grazing) of <20%, 21–50% and >50% corresponded to 'severe', 'intermediate' and 'least' desertified pasture, respectively. The degree of decrease (compared with the healthy example) in reproductive branch length (categories <50%, 51-90%, >90%) and edible grass production (category <30%, 31-65%, >65%) were both determinant for the three categories of desertification. That is to say, if the degree of decrease in reproduction is less than 50% then it is called 'least degraded'. We based our calculation on a 1:250,000 topographic map. The data: plant community height, the degree of decrease in reproductive branch length, and edible grass production, were obtained from Zhenglan Banner Grassland Bureau (2001), which developed the information by working at the local *gacha* (village) level. The investigation was conducted by technicians under the guidance from experts from the Institute of Botany, the Chinese Academy of Sciences. In each *gacha*, 50 sample areas (1m x 1m each), were investigated at a distance of 300m from each other. The data were separated into the above-mentioned four landforms. Thereafter, the average values in plant heights, reproductive branches and edible grass production were respectively calculated to determine the degree of desertification in each *gacha*. Finally, the degree of desertification for the entire Zhenglan Banner was determined.

Of the 10,182 km^2 of land in Zhenglan Banner, almost all the grasslands are affected by desertification at different degrees (Table 1); the ratio of the area between severely, moderately and least desertified degrees was 22: 13: 15. The biodiversity observed can be correctly protected by establishing a core zone. There is a population of 10,507 in the seriously degraded grasslands, or 13% of the total population of Zhenglan Banner.

4.2 Experiment on the potential of natural restoration

The principal methodology used for the conservation of natural resources in Hunshandake Sandland involves using only natural processes to restore the seriously degraded grassland. As the entire sandland is so vast, we therefore began with an experiment at the village scale. This project was carried out on 2,668 hm^2 of severely desertified sandland in Bayin Hushu Gacha, Zhenglan Banner. The land was fenced in 2000 and made free from animal grazing. Meanwhile, an area of 67 hm^2 of lowland, which exhibited considerable fertility, was chosen as a higher productive field. This plot was adjacent to the fenced area to serve as a forage base; supplementing forage shortage resulting from grassland fencing. A variety (*Yinhong*) of corn (*Zea mays* L.) that has a much higher biomass was planted in the forage base employing intensive agriculture technologies, i.e., fertilizers, irrigating systems, and farmland management. Plant biomass (fresh weight) and coverage was collected on July 2001 and 2003 from each of the four habitats: fixed sandy dunes, semi-fixed sandy dunes, shifting sandy dunes, and lowland in five treatments: degraded area, severe degraded area, protected area, interval protected (with rotational grazing), unprotected area and forage base. In each habitat of the 5 treatments, the biomass and coverage was calculated based on the average of 10 randomly selected samples (1m x 1m). The ultimate date of each characteristic for comparison was the mean of 10 replications.

For the restoration of desertified grassland, the experiment has provided remarkably positive results. Comparing biomass and gross vegetative coverage between protected, intervally protected and unprotected areas, protected area yields and coverage increased significantly ($p<0.05$) in two years compared to the unprotected or interval protected areas (Figure 6). Shifting sand dunes did not have any vegetation before this field trial, now biomass found attained some 1,560 g m^{-2} compared to 220 g m^{-2} in the protected area and interval protected areas. Plant community coverage also achieved 60% and 32%, respectively (Figure 7). These indicate that the seriously degraded grasslands will have their coverage and biomass increased if they are fully protected. The nature of vegetation also changed after the area was protected; the vegetation in fixed sandy dunes were mainly dominated by *Artemisia frigida*, *Cleistogens squarrosa* and *Carex duriuscula* before the experiment, after protection these changed to *Agropyron michnoi*, *Kochia prostrate*, etc. The dominant species in vegetation of lowland changed from *Chenopodium glaucum* and *Chenopodium acuminatum* into *Leymus chinensis* and *Elymus dahuricus* etc., which are the best forage species for animals. Still, the number of plant species in samples increased after being protected for only two years, with 121% in protected areas and 74% in partially protected areas on average for all habitats, respectively.

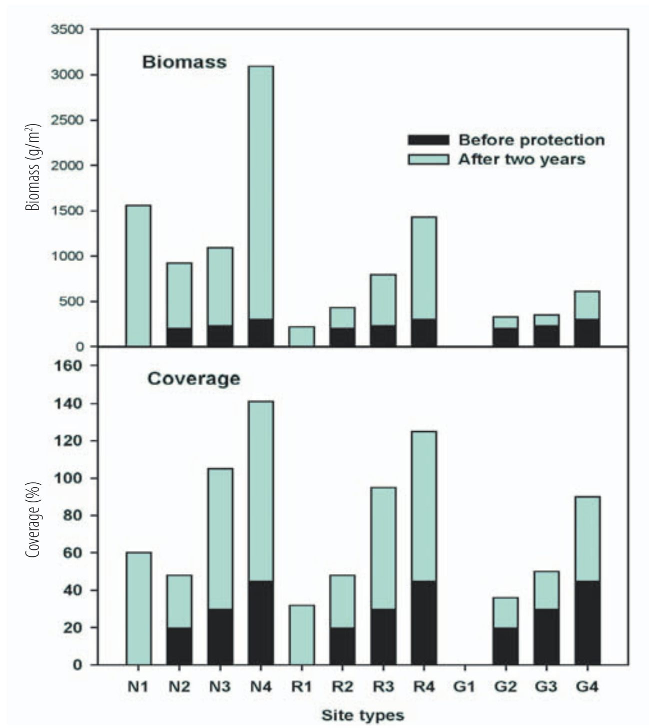

Figure 6 : Changes of biomass and coverage of different plant communities before and after being protected in different sites. In protected area, N1= Fixed sand dunes; N2= Semi-fixed sand dunes; N3= Shifting sand dunes; N4= Lowland. In interval protected area, R1= Fixed sand dunes; R2= Semi-fixed sand dunes; R3= Shifting sand dunes; R4= Lowland. In unprotected area, G1= Fixed sand dunes; G2= Semi-fixed sand dunes; G3= Shifting sand dunes; G4= Lowland. Values are means, n=10.

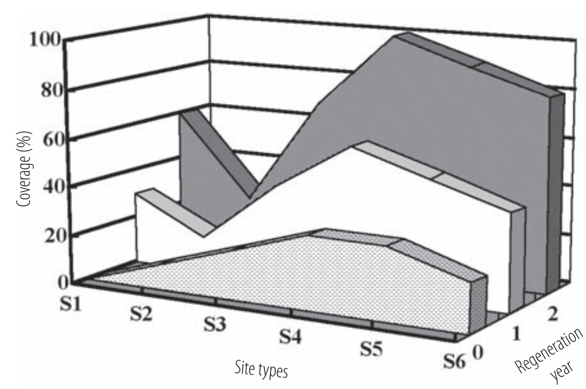

Figure 7 : Changes of coverage of different sites (S1: Shifting sand dunes; S2: Semi-fixed sand dunes; S3: Fixed sand dunes; S4: Lowland; S5; Shrubs in *Salix microstachya*; S6:Grasses in *Salix microstachya*) before and after regeneration.

4.3 Designing a biosphere reserve

Hunshandake Sandland is situated in a natural grassland context where such landscapes are plentiful. There are five microhabitats in Hunshandake: fixed sand dune, semi-fixed sand dune, shifting sand dune, lowland, and wetland. Among these microhabitats different ecosystems develop. It is also worth noting that the special ecosystem of tall grasses and sparse trees dominated by *Ulmus pumila* (Siberian Elm) is a special ecosystem type with many similarities with savanna. However, the exact number of species in Hunshandake Sandland, such as lower and higher plants, lichens and fungi, mammals, birds, fishes and insects, is far from clear.

As concerns the historical and cultural dimension, there are famous relics from what used to be the capital during the Yuan Dynasty (founded in 1253). The importance of this site, together with the many other historical locations, especially in the surrounding cultural and natural environment, presents a problem in that the area is not well understood. Zhengland Banner is the linguistic heart of Inner Mongolia and is famous for its milk productions (milk *toudu*, milk wine, cheese, etc). The people of Hunshandake Sandland are proud of their history and culture and there is a strong need to conserve the cultural diversity.

Hunshandake Sandland is situated in a semi-arid area where precipitation is less than 350 mm but with potential evaporation greater than 2,500 mm. Hence any intense human activities, for instance overgrazing or land cultivation, can easily lead to desertification. The frequency of the dust storms is the result of such destruction to the sandland. This poses serious problems for the people in Hunshandake Sandland who mostly live in poverty. The biosphere reserve concept (Bridgewater, 2002), allows scientists to guide the local communities to use their land wisely while not destroying them. Biosphere reserve enables ecotourism to be developed so as to provide new income sources. Eco-products or eco-jobs could be other solutions to the development of local communities.

Environmental monitoring and ecological research could be conducted if the Hunshandake Biosphere Reserve is established (Figure 8). Currently, there is an ecological long-term research station jointly funded by the Chinese Academy of Sciences and Zhenglanqi Banner. Many institutes and universities have shown great interest in this special area. The Chinese Academy of Sciences, the Chinese Academy of Social Science, the Chinese Academy of Agriculture Science, Peking University, Inner Mongolia University, Inner Mongolia Agriculture University and many other institutions have already chosen Hunshandake Sandland as their research base. Raising awareness of the serious land degradation and dust storms would serve as good examples for environmental education purposes.

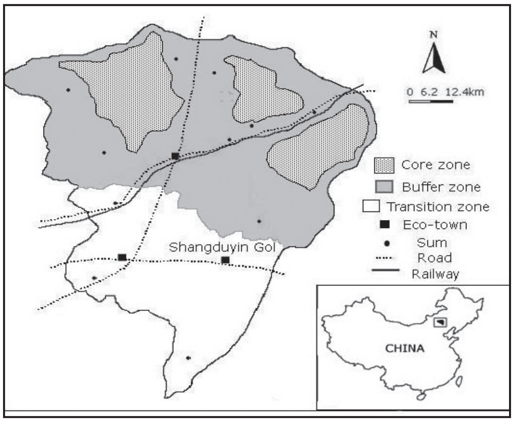

Figure 8 : The designed Hunshandak Biosphere Reserve and zonation areas in the potential nature reserve. *Sum* means towns in Mongolian language.

There are many laws in place that are appropriate for the conservation of the established reserve. In China there are for example, the Grassland Protection law, the Wildlife Protection law, and the Environmental Protection law. The problem is how to manage such a large biosphere reserve once it has been established.

Since the 1980s, a number of projects have been conducted in many places in China to regenerate the degraded ecosystems and acquire greater advances in knowledge (Zhu *et al*., 1999; Zhang & Cheng, 2001). Nevertheless, some projects do not appear to have sound long-time effects owing to their unawareness of the self-regenerating ability and living requirements of the local people. Although a large amount of money was invested in controlling the degraded sandy grassland, the majority of the area still continues to degrade (Jiang, 2003). In view of this phenomenon, the Chinese Academy of Science started a series of projects to study the regeneration model of typical degraded ecosystems as well as the development of the local society. Studies integrating ecology, agriculture, pastoralism, engineering, and sociology were carried out of the loess plateau, the typical grassland, the Tibet plateau, the drought river valley, and the state of the desert in 2000. We chose a large area of degraded grassland with frequent production and everyday activities to develop a pathway to regenerate the degraded grassland through natural processes with the strategy of 'nurture the land with land' and 'intensive land-use'.

The preliminary plan was to leave the severely desertified grassland to be left in its natural state, which would stimulate the re-establishment of biodiversity, wildlife and vegetation in the three core zones. Forage bases would be constructed in the buffer zone to compensate for the forage shortage brought about by reducing the grazing area; the people now living in the severely degraded land (population of 10,507) will be relocated to three towns. This in turn will satisfy the development requirements of the three towns with an increase in the ratio of urbanization by 40–50%. The town of Shangduyin Gol in Hunshandak Sandland would be enlarged into a centre city. In Zhenglan Banner, there is an estimated 67,000 hm^2 of lowlands with a high production potential. If all the lowlands are reasonably managed, the grass yield potential could reach up to 300 million RMB (calculated from 2,250 kg/ha). Furthermore, ecotourism and culture-tourism is estimated to produce an income of 50 million RMB (Zhenglan Banner Tourism Bureau, 2001), stock production and further processing and related agri-business would produce an income of 950 million RMB, and income from other industrial and commercial activities would bring in another 50 million RMB (Zhenglan Banner Government, 2000).

5. Practices implemented for soil and water conservation

5.1 Water resources

Historical information was obtained or bought from the Zhenglan Meteorological Station and Forest and Water Resource Bureau. The distribution of main lakes and rivers in the whole Zhenglan Banner was verified on site. The geographical positions were confirmed with GPS (Allis Communication Company Ltd, Taiwan).

In Zhenglan, where Hunshandake is mainly located, there are some 155 small lakes with areas greater than 0.2 km^2, however most of them exist only temporarily in the summer season. The distribution of main *naoers* (meaning lake in Mongolian) with the corresponding water surface, the amount of water, depth of lakes and elevations of the lake in Zhenglan Banner of Hunshandake Sandland is given in Table 2. The average river flux of the groundwater system was estimated to be 22,600,000m^3/year. In the rainy season, the groundwater collection area can be extended to 80 km^2, with water retention of 110,500,000 m^3. However, this figure decreased to 13,150,000m^3 in the dry season. However, most of the water was saline with poor water quality and low utilization values. The underground water resource nevertheless was relatively plentiful owing to the fact that sandland can hold more water than other soil types; some 456,150,000m^3 proven reserves could be used.

Series	Name of Naoer	Area km^2		Depth, m		Water amount (million m^3)	Elevation m
		Water accumulated	Water surface	Maxmum	Average		
1	Haolitu	3.98	1.5	1.96	1.28	1.63	1368
2	Baiyin	7	2.595	2.24	1.535	5.58	1350
3	Dage	1.85	1.6	3.15	2.325	29.76	1339
4	Haga	3.308	2.22	0.5	0.35	0.78	1329
5	Chagan	14.28	9.2	2	1.5	10.58	1316
6	Dudao Shari	4.55	3	0.4	0.3	0.90	1315
7	Yihe	4.59	3.85	0.95	0.6	2.31	1299
8	Xilitu	2.1	1.5	1.3	0.95	1.43	1293
9	Zhunsaihan	3.65	2.91	0.95	0.6	1.48	1292
10	Dunda Saihan	2.4	1.45	1.04	0.72	1.04	1290
11	Zhage Sitai	7.5	1.09	1.15	0.7	3.50	1230
12	Sanggen Dalai	5	2.8	0.95	0.65	1.82	1230
13	Baoshadai	28.55	10.5	1.5	0.8	8.40	1220
14	Bayin Hutu	1.65	1.26	0.96	0.6	0.76	1301
Total		**90.41**	**33.84**			**67.68**	
Average		6.46	2.42			4.83	1298

Table 2. The distribution of main *naoers* (lakes) in Zhenglan Banner of Hunshandake Sandland.

5.2 Soil seed bank

Soil seed banks and above-ground vegetation from a series of degraded sand and several aerial seeding sites undergoing restoration in the Hunshandak Sandland were sampled to explore the potential of the seed bank as a source of species which can re-establish themselves under natural restoration conditions. Areas of degraded sands that had been fenced and subjected to either tree planting or aerial seeding were also investigated. The aims of soil seed bank study were therefore to clarify whether or not the seed banks in degraded sandlands are large enough to support significant re-vegetation as well as understand how fencing and aerial seeding affects the species composition of soil seed banks. Such soil seed bank studies can help us to explore the degree of correlation between seed banks and vegetation succession in chronological sequence.

Soil seed bank samples were taken from 3 February to 25 March 2002 prior to seed germination. At all nine sites, ten 30m x 30m permanent quadrats were established, within which ten subplots of 25cm x 25cm x 5cm were collected for one sample. Three replicates were taken from each quadrat. Soil samples were washed using a sieve with a mesh size of 0.15 mm. The residues containing the seeds from each sample were spread out evenly on sterilized potting soil in seed trays. The trays were then placed in a greenhouse for germination. Seedlings were identified, counted and removed as soon as possible to avoid mixing by subsequent germinated seedlings. The samples were treated with gibberellic acid (1 g L^{-1}) to stimulate the germination of dormant seeds.

The vegetation was investigated within the ten 30 m x 30 m quadrats from where the soil cores for the seed bank study at all sites were taken. The percentage cover of each plant species was assessed. These data were then aggregated to compute frequency values within each site. For each sample, every species was separated and its relative dry weight was determined after drying at 80°C for 48 h.

5.3 Net primary production (NPP) of the sandland ecosystem

Scientists from both China and the world still have little information on the structure and function of the sparse forest grassland ecosystem such as found in Hunshandake Sandland thereby making it urgent to estimate its potential biomass and NPP before possible severe degradation occurs. Moreover, a better understanding of such a special ecosystem would be helpful towards its effective restoration and conservation.

In order to determine the proportions of the five habitats (shifting sand dune, semi-fixed sand dune, fixed sand dune, lowland, and wetland) of the Hunshandake Sandland, we surveyed a 10 km long and 100 m wide transect in the restoration research area in a south to north direction, approximately vertical to the main sand ridges. Habitat and vegetation were documented for every 100 m interval. *Ulmus pumila* is almost the only tree species found; other tree species include *Malus baccata, Betula fruticosa* and *Prunus padus* but the numbers are scarce. The diameter at breast height (DBH) was 1.3m aboveground with height (H) and crown diameter (CD) being determined for all the *U. pumila* individuals. For other species, only DBH > 5 cm was measured.

Six well-developed trees, spanning different DBH classes, were selected as standard sample trees. Their DBH, H and CD were measured after felling. The stems, branches and leaves were separated and weighed. The live coarse roots ($d \geq 5$mm) and small roots (2mm < d < 5mm) were dug out, sieved and collected then weighted. All the parts of the trees were sampled and dried at 85°C until a constant weight was obtained to calculate in scale the dry biomass of the different parts. We applied the values of the sample trees to fit power allometric relationships between DBH and biomass as the power function is the most widely used relationship in tree biomass estimations. Stem, branch, leaf, coarse root, and small root biomass was calculated by combining the allometric relationships and the information from every tree dimension in every habitat at the stand level.

Four soil core (inner diameter of 8 cm) samplings in four directions were drilled to a depth of 1m at a distance of half the crown diameter from each sample tree base before excavation. All the small roots and fine roots ($d \leq$ 2mm) were separated manually and rinsed of sand. Live and dead roots were rated on the criterion that live roots are resilient, flexible and light-coloured while dead roots crumble, are fragile and dark-coloured. All were dried to constant weight at 85°C. The ratio of live small root biomass to fine root biomass was thus obtained. The biomass of live fine roots can then be calculated from the live small roots biomass at the stand level.

Five 4 m^2 clipping plots respectively for fixed, semi-fixed and shifting sand dunes, and five 1m^2 plots for both lowlands and wetlands were investigated in late August when biomass was highest. The aboveground biomass was clipped and collected manually. Belowground biomass was explored by soil cores to a depth of 50 cm at 10 cm intervals. Wetland soil cores were not investigated according to different layers; there were 15 soil cores for each habitat. Belowground live biomass was rinsed out. All the parts were dried to constant weight at 85°C and weighed. The amount of standing dead matter and detritus was omitted.

5.4 Rainfall use efficiency of the sandland ecosystem

The NPP of stems, branches and coarse roots was calculated as was their mean biomass increments over the last five years (2001–2006). The NPP of leaves was considered to be the same amount as its biomass. As for the NPP of small and fine roots, which are fast turnover parts, we assumed small and fine root turnover ratios to be 0.5 and 1, so NPP can be calculated by multiplying biomass by turnover ratios respectively. Litter fall from trees was collected every month from April to August using 15 x 1m^2 litter fall traps placed randomly in a 50m x 50m fixed sand dune plot. Leaves, twigs and miscellaneous were separated, dried at 85°C and weighed. Litter fall from the other four habitats was calculated in proportion to their tree densities relative to fixed sand dune tree density.

The aboveground and belowground NPP of fixed, semi-fixed and shifting sand dunes were assumed to be equal to the corresponding peak aboveground and belowground biomass, respectively. Lowland and wetland aboveground NPP adopted their peak aboveground biomass, while the belowground NPP equaled the difference between the maximum and minimum biomass. The minimal biomass was achieved from the 15 soil core samples (inner diameter of 8cm) dug before the growing season of 2005 to a depth of 50 cm in each habitat.

After we obtained the NPP data, the rainfall use efficiency (RUE) in an ecosystem level of sandland was calculated. This was completed by the end of October of 2006, with the RUE from other ecosystems such as savanna, desert, and temperature forest being compared. The value of RUE is calculated by NPP/rainfall; rainfall data comes from the recent 10-year Zhenglan Banner average.

6. Income-generating activities to diversify the economic base at household levels

6.1 Establishment of a commercial company and training of local people

With the help of scientists from the SUMAMAD Hunshandake team, a company was set up in 2003 and has been running since 2004, with forage, milk, meat, live animals and ecotourism as their main products. Traditional processing of milk products and chicken farming are the new income-generation activities of this recently established company. Training, related to the two animal product industries, was carried out. Five families (involving one or two members) were involved in the chicken farming and were trained up by a veterinary from Hebei Province. Ten women were trained to transform the local milk resource into the traditional Mongolian milk tofu. Five core members were trained twice by three Malaysia volunteers to learn how to run a business. Fifty households have been involved in the company since the start of the project, and up to now all have been trained. The main methodologies used in training are lectures (computer and projection tools included), person-to-person demonstrations, discussions and practice sessions.

6.2 Chicken farming in the grassland

China's many varieties of grassland cover an area of 1 billion acres. They account for 41% of the country's total area, and is equal to 3.3 times the area of its cropland. Yet these vast grasslands cannot feed the animals they are home to, which together account for one-third of China's livestock. Many years of overgrazing has led to the deterioration of 90% of China's grasslands giving rise to environmental problems such as the infamous sandstorms.

Yet China has 4.7 billion chickens and an annual demand of 3.7 chickens per person. However, farmers squeeze chickens into wire cages and overuse additives to fatten them as quickly as possible. This makes them ready for slaughter in 45 days compared to 200 days for a free-range chicken. These unnatural meat-production methods are contributing to obesity in our cities and help spread avian flu that brings about poor food hygiene and endangers public health as well as inviting criticism of China's record on animal welfare issues. The wide open spaces poultry need are not found in farmyards, much less in wire cages; the space can however be found on the grasslands. Chickens present no danger to the grassland and can help control pests. In the future, the huge quantities of chicken and eggs that China needs could come from these grasslands.

Figure 9 : Chickens in the grasslands can on one hand solve the food pollution problems in inland China and on another hand control insects, thus increasing the income of the local people.
(Photo by Gaoming Jiang)

In 2005 and 2006, some 15,000 chickens were raised by five families in the 400 mu (15 mu equals 1 hectare) from the village of Bayinhushu Gacha, Hunshandake Sandland (Figure 9). In 2007, our project team helped two families raise 2,000 hens, and 100,000 eggs were expected to be produced as a result. This new income-generation activity was first carried out in China's true grasslands with financial support from the SUMAMAD project.

6.3 Traditional tofu production

Traditional milk tofu production has been encouraged, and the SUMAMAD research members helped the local people open the market. Ten families who produce the traditional Mongolian milk tofu have been involved. Traditional Mongolia tofu production can also increase the price of the milk. Compared with only selling milk, tofu production can increase the price by 20% per kilogram. However, this is very labour intensive and could be further improved by replacing some of the labour by machine.

6.4 Ecotourism

Since 2002, Hunshandake Sandland has become increasingly well known as scientists from the project team have presented scientific and social findings in various media (newspaper, television broadcast, Internet, journals). Visitors from both home and abroad have shown interest in the sandland landscape and the Mongolian culture and people such that ecological and cultural tourism has now become a new income-generation activity on our project site. Ecotourism is also actively designed and encouraged by our research team. Besides the beautiful landscape, we help local families build family hotels. For example, Nasen Ruritu's family can host up to ten visitors a day, with facilities being built such as road transportation, bedrooms, toilets, deep-ground wells, and cooking gas stoves. Some of the funds come from Zhenglan Banner as per a requirement of the project team from the Chinese Academy of Science.

6.5 Response from the local population

Investigation into the social aspects of the communities revealed that since 1990 more than 90% of local families invested a sizeable sum of money in livestock spending, on average 10,000 RMB, to buy forage grass from distant areas. The higher-income families invested between 10,000 and 13,0000 RMB to purchase forage grass, while middle-income families invested about 6,000–7,000 RMB (Table 3). Since the implementation of the ecological

Type of family	1998		1999		2000		2001		2002	
	Grass	Forage	Grass	Forage	Grass	Forage	Grass	Forage	Grass	Forage
High-income	5,000	3,000	5,500	5,000	10,000	3,000	4,000	500	2,000	500
Mid-income	1,500	3,500	2,000	4,000	3,000	5,000	2,500	500	1,000	500
Low-income	1,000	0	800	0	800	0	600	0	400	0

Table 3. Average cost for the forage and grass in winter from 1998 to 2002 in Bayinhushu village, the SUMAMAD project site (Unit: RBM). Since 2003, no family buy forage and grass instead they began to sell grass with an average income of 10,000 to 20,000 RMB.

restoration experiment in 2001, local families have spent only 1,500 RMB in order to obtain enough forage grass (ensiling corn and hay) for livestock. Ensiling corns have the benefit of keeping domestic animals fat. However, since 2003, the 2,667 ha fenced sandland produces a vast amount of grassland (more than 288 million tons), an elevated production that continues today. In 2006, nearly half of the families benefited from selling grasses, with an additional annual income of 10,000 to 20,000 RMB.

The production of milk in 2001 is twice that in 2000. The highly efficient forage grass produced a net profit of about 30,000 RMB after meeting the requirements of the domestic animals, thus after feeding his animals the local farmer can still sell the remaining forage to satisfy the requirements of all the domestic animals in the local village. Furthermore, the naturally restored grassland not only brings about ecological benefits it also creates significant economic ones. Consequently, the income of local people is increasing despite the fact that some of the pasture has been fenced off (Liu *et al*., 2003). The average income of Bayinhushu village is 50% higher than Herisitai town. Since 2003, the local people have begun to sell grasses from the naturally restored vast grassland. At the beginning of the project they questioned the results and refused to cooperate, now however everyone is happy with the project and they fully cooperate in SUMAMAD activities such as chicken farming, ecotourism, dry grass processing, improvements in living standards and so on.

7. Results obtained

7.1 Seed bank of Hunshandake Sandland

A series of naturally restored habitats of Hunshandake Sandland were compared for species composition, soil density of soil seed banks and vegetation composition (Table 4), and with serial seedling sites (Table 5). Thirty-six species were identified in soil seed banks in all naturally restored habitats, with 41 species being found in vegetation. Conversely, five species in seed banks and three species in vegetation were noted after the land was fenced-off for two years. Only two pioneer species, *Agriophyllum squarrosum* and *Setaria viridis* was found in the seed bank at the first year of enclosure. However, the numbers increased to 25 if the grassland was fenced for a period of 15 years. As for the aerial seeding sites, seed banks contained some indigenous species but a very low number of their seedlings were recorded; the plant community was predominated by alien shrub species such as *Artemisia ordosica* and *Hedysarum scoparium*, which indicates that the establishment of a large number of introduced species might hinder the germination of certain indigenous pioneer species. Seed density increased from 459 ± 76 seeds per m^2 at the second year of enclosure to 3351 ± 694 seeds per m^2 at the fifth year of enclosure. The seedlings of *Ulmus pumila*, an indigenous tree species were well established in all naturally-restored sites, however this did not occur in the

Species names	Frequency in vegetation (%)	Seed bank density (seeds m^{-2})	Species names	Frequency in vegetation (%)	Seed bank density (seeds m^{-2})
NRS1			*Thellungiella salsuginea*	53	40 ± 10
Agriophyllum squarrosum	93	120 ± 23	*Leymus chinensis*	87	160 ± 17
Setaria viridis	0	30 ± 9	*Eragro-stis poaeoides*	30	92 ± 16
Total		**150 ± 32**	*Bromus inermis*	50	160 ± 18
NRS2			*Asparagus cochinchinensis*	20	9 ± 2
Bassia dasyphylla	83	180 ± 26	*Cleistogenes squarrosa*	53	926 ± 53
Corispermum heptapotamicum	90	124 ± 20	*Chloris virgata*	70	1238 ± 82
Setaria viridis	53	85 ± 15	*Cynanchum thesioides*	10	0
Agriophyllum squarrosum	0	50 ± 9	*Salsola collina*	27	37 ± 10
Leymus secalinus	0	20 ± 6	*Astragalus melilotoides*	7	0
Total		**459 ± 76**	**Total**		**3302 ± 315**
NRS4			**NRS15**		
Hedysarum scoparium	26	20± 5	*Artemisia intramongolica*	97	2529 ± 590
Salix gordejevii	23	0	*Chenopodium glaucum*	72	145 ± 90
Caragana microphylla	19	6 ± 2	*Euohorbia humifusa*	72	116 ± 35
Ulmus pumila	36	0	*Setaria viridis*	72	268 ± 114
Cleistogenes squarrosa	62	276 ± 31	*Lespedeza sp*	59	60 ± 30
Leymus secalinus	78	120 ± 6	*Aristida adscensionis*	59	96 ± 72
Melissitus ruthenicus	53	50 ± 10	*Leymus secalinus*	59	8 ± 2
Bromus inermis	45	60 ± 18	*Salsola collina*	53	60 ± 29
Setaria viridis	72	120 ± 4	*Corispermunm sp*	53	61 ± 27
Dianthus chinensis	23	0	*Melissitus ruthenicus*	53	20 ± 10
Thellungiella salsuginea	53	50 ± 10	*Bassia dasyphylla*	53	9 ± 4
Bassia dasyphylla	83	180 ± 26	*Penisetum centrasiaticum*	53	5 ± 3
Corispermum heptapotamicum	90	124 ± 20	*Psammochloa villosa*	52	4 ± 2
Potentilla sp	53	85 ± 15	*Ixeris denticulate*	33	4 ± 3
Cynanchum thesioides	10	0	*Erodium stephanianum*	33	7 ± 2
Agriophyllum squarrosum	0	100 ± 9	*Gueldenstaedtia stenophylla*	19	0
Bupleurum sp	33	0	*Artemisia lavandulaefolia*	19	9 ± 6
Total		**1191±156**	*Artemisia ordosica*	20	64 ± 43
NRS8			*Cleistogenes squarrosa*	13	67 ± 40
Hedysarum scoparium	17	20 ± 6	*Chloris virgata*	13	2 ± 2
Salix gordejevii	23	0	*Cynanchum thesoioides*	13	0
Ulmus pumila	33	0	*Calamagro-stis epigejos*	13	0
Caragana microphylla	13	6 ± 2	*Euphorbia esula*	13	2 ± 1

Species names	Frequency in vegetation (%)	Seed bank density (seeds m^{-2})	Species names	Frequency in vegetation (%)	Seed bank density (seeds m^{-2})
Artemisia ordosica	37	0	*Inula salsoloides*	13	0
Dianthus chinensis	23	8 ± 4	*Kummerowia striata*	13	0
Bupleurum sp	33	17 ± 9	*Potentilla bifurca*	0	7 ± 1
Bassia dasyphylla	0	180 ± 42	*Eragro-stis poaeoides*	0	16 ± 9
Agriophyllum squarrosum	0	169 ± 25	*Agriophyllum squarrosum*	0	20 ± 7
Psammochla villosa	63	0	*Portulaca oleracea*	0	4 ± 1
Polygonum divaricatum	83	20 ± 8	*Tribulus terrestris*	0	2 ± 2
Achnatherum sibiricum	70	120 ± 11	**Total**		**3,351 ± 694**

Table 4. Species composition, seed bank density and frequency of plant species in vegetation five naturally restored sites in Hunshandake Sandland, China. Data were mean ± standard error of three replicates. NRS1, NRS2, NRS4, NRS8 and NRS15 were fenced respectively in 2001, 2000, 1998, 1993 and 1987.

aerial seeding habitats. Our investigation showed that the seed bank was large enough to naturally restore the degraded lands in Hunshandake Sandland. We therefore suggest that it is not essential to introduce alien species to enhance vegetation coverage in this region.

7.2 Seed bank composition

A total of 36 species were recorded in the soil seed banks of all five naturally restored sites. Species number increased with time after fencing and progressed in terms of restoration succession. For example, there were two species in the seed bank in the first year following enclosure, increasing to 25 after 15 years i.e. after fourteen years of restoration. Perennial species gradually came to dominate the seed banks, with their numbers increasing continually with restoration progress. However, there were no significant differences between 8 and 15 years of natural restoration indicating that a climax community has been established. As far as functional types are concerned, over 60% of species in seed banks are C_4 plants after the first and second year of fencing, while C_3 plants constituted more than 50% of seed banks at the eighth and fifteenth year. Legumes appeared by the fourth year (20% in vegetation cover) but the percentage declined by the fifteenth year of enclosure. Some seventeen species were recorded at the aerial seeding sites composed of both indigenous and alien species. The number of species increased with time. More than 50% of species in the seed banks of all four sites were perennial, and C_3 plants represented 40–50% of species composition except for the first year aerial seeding site. Legumes were found at all sites as such species was specifically introduced.

7.3 Biomass of Hunshandake Sandland

The crown dimensions and biomass of ten sample trees were used to establish the logarithmic allometric relationships between DBH and biomass of different components. All the allometric relationships fitted for biomass estimation were highly significant ($P < 0.001$). Combining the biomass of every habitat with corresponding area proportion, we computed the average biomass of elm sparse forest grassland ecosystem to be 20.42 Mg ha^{-1}, of which tree biomass accounts for 10.6%. Siberian elm tree biomass could then be estimated. The ratio of belowground to aboveground biomass was 3.5. Among the five habitats in Hunshandake Sandland, biomass was highest in wetland and lowest in shifting dunes. However, the biomass in lowland took up to 77% of the average biomass of sparse forest grassland. The contribution from belowground biomass was about 4.5 fold that of aboveground in wetland and lowland where rhizomatic, gramineous herbs were dominant species (Table 6). The contributions from trees exceeded 50% in shifting and fixed dune but in lowland, biomass from the herbaceous layer was commonplace.

Species names	Frequency in vegetation (%)	Seed bank density (seeds m^{-2})	Species names	Frequency in vegetation (%)	Seed bank density (seeds m^{-2})
ASS1			*Cleistogenes squarrosa*	13	9 ±6
Agriophyllum squarrosum	0	120 ± 23	*Leymus secalinus*	13	14±8
Setaria viridis	0	30 ± 9	*Thellungiella salsuginea*	13	0
Caragana microphylla	38	22±10	*Astragalus sp.*	9	9±4
Artemisia ordosica	93	0	*Eragro-stis poaeoides*	9	10± 8
Hedysarum scoparium	45	18±4	**Total**		**355±92**
Total		**190 ± 25**	**ASS7**		
ASS2			*Hedysarum scoparium*	38	35±19
Setaria viridis	39	80 ± 15	*Caragana microphylla*	46	68±19
Agriophyllum squarrosum	0	19 ± 9	*Artemisia ordosica*	71	130±23
Leymus secalinus	0	17 ± 6	*Setaria viridis*	42	80 ± 15
Corispermum heptapotamicum	0	23 ± 15	*Agro-pyron cristatum*	36	167 ± 25
Caragana microphylla	64	22±10	*Kochia prostrata*	24	0
Artemisia ordosica	93	20±7	*Chamaerhodos erecta*	11	0
Hedysarum scoparium	58	0	*Cleistogenes squarrosa*	42	116 ± 35
Total		**181 ±62**	*Ulmus pumila L. var. sabulosa*	30	0
ASS5			*Potentilla sp*	16	0
Hedysarum scoparium	38	35±9	*Corispermunm sp*	43	45 ± 15
Caragana microphylla	46	68±19	*Polygonum sp*	25	8 ± 2
Artemisia ordosica	71	130±23	*Thellungiella salsuginea*	20	14 ± 6
Setaria viridis	42	80 ± 15	*Chloris virgata*	13	2 ± 2
Cynanchum thesioides	9	0	*Portulaca oleracea*	0	4 ± 2
Dianthus chinensis	12	0	**Total**		**669± 213**

Table 5. Species composition, seed bank density and frequency of plant species in vegetation of four aerial seeding sites in Hunshandak Sandland, China. Data were mean ± standard error of three replicates. ASS1, ASS2, ASS5 and ASS7 were fenced after aerial seeding in 2001, 2000, 1997, 1995,

Tree biomass was found to be the highest in fixed dunes and the lowest in wetland, displaying the same trend as tree density. The root/shoot ratio of tree biomass was about 1.4 in all habitats (Figure 10). The biomass ratio of live small roots to live fine roots was 1.49 ± 0.2 (n = 10). The difference between live and dead small root biomass density in soil was more significant than that of fine root ($P < 0.01$). Siberian elm's small and fine root vertical distribution revealed that root density peaked at a depth of about 55 cm regardless of whether they were live or small roots, but live fine root density was higher than that of live small root above the 45 cm layer. The average herbaceous layer biomass of the sparse forest grassland in Hunshandake was 18.26 Mg ha^{-1}. The biomass of herbaceous layers was highest in wetland, about 190 times greater than the lowest found in shifting dunes.

For herbage only, about 85% of the root biomass was allocated in the upper 30 cm layer of the four habitats investigated.

7.4 NPP of Hunshandake Sandland

Based on every habitat's area percentage, the average NPP of sparse forest grassland was estimated to be 10.65 Mg ha^{-1} yr^{-1}, of which 1.2% of the contribution comes from trees, 76.8% from lowland, and 65% from belowground (Table 6). Among the five habitats, the NPP decreased from wetland's 33.5 Mg ha^{-1} yr^{-1} to shifting dunes' 0.4 Mg ha^{-1} yr^{-1}. The belowground net primary production (BNPP) was higher than aboveground net primary production (ANPP) in wetland, lowland, and fixed dunes. The fraction of tree NPP in terms of total NPP in every habitat varied from 10.1% in shifting dunes to almost zero in lowland and wetland. Additionally, tree NPP was highest in fixed dunes and lowest in wetland. The aboveground component contributed 69% to the average tree NPP. The turnover rates of small and fine roots were 0.15 ± 0.03 and 0.24 ± 0.03 (n = 10), respectively. Herbaceous layer NPP was highest in wetland, followed by lowland. Their minimum belowground biomass was 33.3 ± 1.5 (n = 15) and 14.5 ± 0.6 (n = 15) Mg ha^{-1}, respectively. In the other three habitats the herbaceous layer NPP dropped from fixed to shifting dunes. The lowland contribution was the highest for the average herbaceous layer NPP.

7.5 Rainfall use efficiency

Le Houérou (1984) presented the concept of rain use efficiency (RUE), which is defined as the quotient of ANPP (kg ha-1 yr-1) by mean annual rainfall (mm). According to the correlation between climate zone and its vegetation, RUE does not vary significantly among ecosystems. In other words, where the mean annual precipitation (MAP) is high, its net primary production (NPP) increases accordingly and vice versa. Yet there are some variations among the RUE of the eight

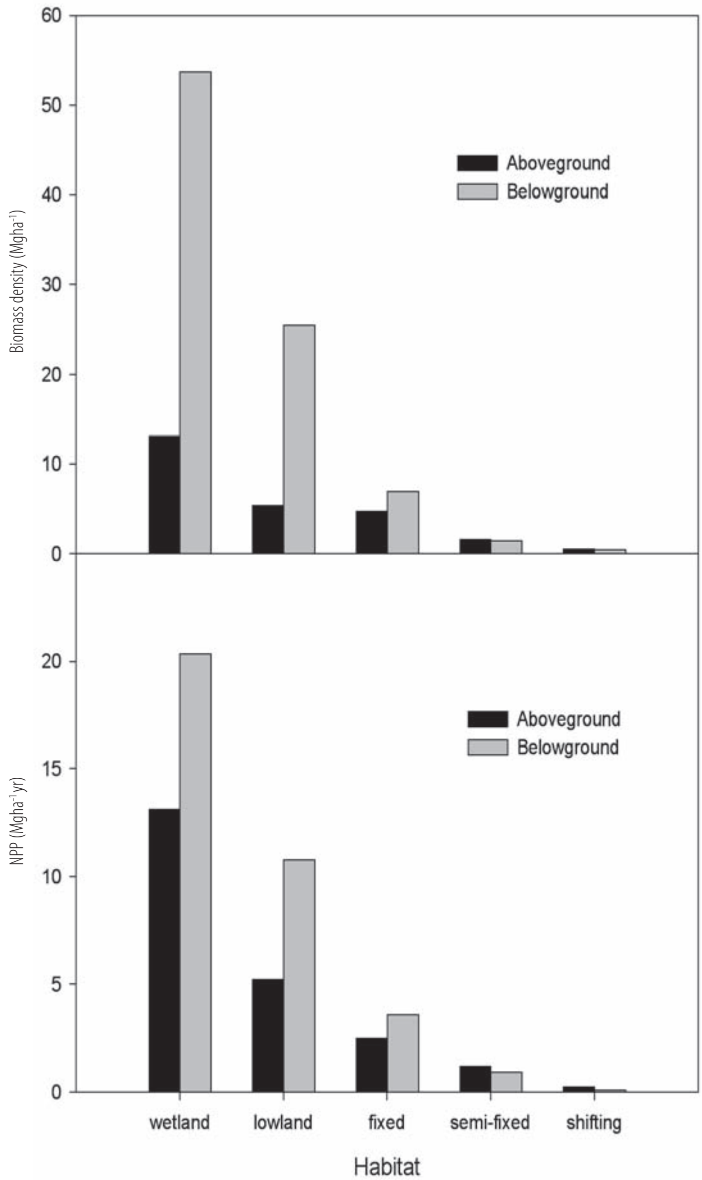

Figure 10. Comparison of above- and belowground biomass density (upper) and NPP (lower) of the five habitats of Hunshandake Sandland.

main ecosystem types. High RUE usually appears in ecosystem with low MAP. Although its NPP is often lower than other ecosystems such as tropical forest, the RUE may be higher since the plants have evolved more efficient adaptive strategies in arid environments

	Fixed sand dunes		Semi-fixed sand dunes		Shifting sand dunes		Lowland		Wetland	
	Biomass	NPP	Biomass	NPP	Biomass	NPP	Biomass	NPP	Biomass	NPP
Aboveground										
Tree										
Stems	1.18	0.03	0.20	0	0.13	0	0.07	0	0	0
Branches	1.10	0.02	0.19	0	0.12	0	0.06	0	0	0
Leaves	0.15	0.15	0.03	0.03	0.02	0.02	0.01	0.01	0	0
Litterfall		0.04		0.01		0		0		0
Herbaceous layer	2.28	2.28	1.17	1.17	0.26	0.26	5.22	5.22	13.12	13.12
Belowground										
Tree										
Coarse roots	3.38	0.08	0.57	0.01	0.36	0.01	0.20	0	0	0
Small roots	0.08	0.04	0.01	0.01	0.01	0.01	0	0	0	0
Fine roots	0.05	0.05	0.01	0.01	0.01	0.01	0	0	0	0
Herbaceous layer	3.46	3.46	0.89	0.89	0.09	0.09	25.3	10.8	53.68	20.37
Total	**11.68**	**6.15**	**3.07**		**1.00**		**30.86**		**66.80**	**33.49**
Percentage of trees	51	7	33	3	65	13	1	0	0	0

Table 6. Biomass (Mg ha^{-1}) and NPP (Mg ha^{-1} yr^{-1}) by components for every habitat of Hunshandake Sandland.

Ecosystem type	NPP (t ha^{-1})		MAP (mm)	RUE* (kg ha^{-1} yr^{-1} mm^{-1})	
	W & L	S & R		a	b
Tropical rain forest	22	25.0	2500-4500	4.9-8.8	5.6-10
Temperate evergreen forest	13	15.5	1000-1500	8.7-13	10.3-15.5
Temperate deciduous forest	12		500-1000	12-24	15.5-31
Boreal forest	8	3.8	400-500	16-20	7.6-9.5
Savanna	9	10.8	> 1000	< 9	< 10.8
Temperate grassland	6	7.5	150-1200	5-40	6.3-50
Desert and semidesert scrub	0.9	2.5	< 250	> 3.6	> 10
Tundra		1.4 1.8	100		14 18
Hunshandake Sandland	11.06		370.23	30	

Table 7. Comparisons of NPP, MAP, and RUE of various ecosystem types and Hunshandake Sandland

* RUE = total NPP/MAP; a and b mean RUE calculated from NPP in W & L and S & R columns.

i.e. less water produces more dry matter. We could put the RUE of Hunshandake Sandland into the system to evaluate its rain-use characteristics.

The 40-year (1960–1999) mean annual precipitation in this area was 370.23 mm according to the climate records from Zhenglan Banner Observatory, so the RUE of sparse forest grassland ecosystem in Hunshandake was calculated to be 10.1. The result showed that Hunshandake had high RUE in contrast with its relatively low MAP (Table 7).

7.6 Benefits from income-generation activities for the local people

The biomass, height and coverage of plant community in most of the habitats have significantly increased after

5 years of regeneration. The average biomass was 1012 g m^{-2} and the mean coverage reached 60 % in shifting sand dunes, where it was seriously degraded with bare sand dunes before enclosure (Figure 11). In fixed sand dunes, total community coverage has grown threefold compared to the control (Figure 12). In comparison, the biomass in lowland increased by ninefold. In this case study, we suggest that the ecological restoration of Hunshandake degraded sandland should depend largely on natural processes rather than artificial vegetation reconstruction.

The socio-economic situation of the communities also improved significantly. For example, the survival rate of young stock increased by 10%, and milk production increased by 200%. In 2003, we helped local people establish a company, which was run after 2004, with chicken raising and traditional milk Mongolian tofu as the main products. Some 15,000 chickens were raised in grasslands covering 500 Mu (1 hectare = 15 Mu), 3,000 chickens died from illness or were eaten in the grassland by wild eagles or foxes. As the grasslands provide a more natural ecological habitat for the chickens they can be sold at higher prices than factory chickens. The invested capital was 150,000 RMB (100,000 RMB for the facilities, 20,000 RMB for chicken feed, 30,000 RMB for labor costs), and the total output was 240,000 RMB, therefore a net income of 90,000 RMB was achieved. Compared with traditional cattle breeding (300 RMB/ha), the new way of using land by raising chickens can increase income ninefold (2,700 RMB/ha).

In the project site the entire household is the biggest beneficiary. Some 288,000 kg (dry matter) of hay has been harvested in the fenced experimental site. The current price is 0.3 RMB/kg, which means each family will see a benefit of 12,000 RMB (72 families in the village). Before our experiment, and because of serious land degradation, each family had to spend 10,000–20,000 RMB to buy forage (see section 6.5). So, the local farmers are happy to harvest and sell their own forage (Figure 13).

Figure 11. Seriously degraded Hunshandake Sandland in 2000 before the demonstration project (supported by the Chinese Academy of Sciences, continued funded by SUMAMAD in 2004).
(Photo by Gaoming Jiang)

Figure 12. Naturally resorted tall grasses in Hunshandake Sandland after the demonstration project. Photo was taken in 2005 when the rainfall of the year is only 60% of the annual average value. Such high grassland production continued from 2002 to the present day.
(Photo by Gaoming Jiang)

Traditional Mongolia tofu production can also increase the price of the milk. Compared with only selling milk, tofu production can increase the price by 20 %. Each family can thus make a profit of 5,500 RMB in selling

Figure 13. Local ranchos from the Bainyin Hushu Gacha (village) of the Hunshandake Sandland are happy to harvest their own grasses. Photo by Gaoming Jiang.

milk tofu. However, this is very labour intensive and could be further improved by replacing some of the labour with machines. Another small outcome is ecotourism. If we take Mr. Nasen Wuritu's family as an example, in 2006, 24 visitors stayed in his home over a period of 11 days with a profit of 7,920 RMB.

8. Recommendations for sustainable dryland management

We believe that human infringement is the predominant reason for grassland degradation, while natural factors remain secondary. Reduction of sandstorm occurrence can be achieved by reducing livestock grazing pressure on the depleted ecosystems together with satisfying both production and living requirements, this will allow the native vegetation to become re-established naturally and prevents the need for planting exotic trees or aerial sowing. We have the following recommendations for restoring the degraded grassland as well as to achieve the sustainable management of drylands in Inner Mongolia:

(1) Incentives should be offered to the population of the regions concerned so that they can relocate to areas with better natural conditions or towns. The quality of life is so poor that local people barely survive in the degraded areas preferring to migrate to areas with better natural living conditions. Centralization of the nomadic population into specific areas would allow a more economically viable community to develop. Improved forage grass strain development and cultivation should be encouraged which, together with better animal husbandry in fenced areas, would allow for better milk, mutton and beef production.

(2) Restoration of degraded ecosystems is well developed and takes advantage of natural processes. In 1959, the Australian government removed all livestock and people from a small town in New South Wales in order to restore the degraded grassland without any artificial assistance (Walker, 1976). After 16 years of restoration, the coverage and height of grasses and scrubs improved significantly (Noble, 1997). There are still many successful examples of ecosystem revival by natural processes in other areas (Dyson, 1996; Bradshaw, 2000; USDA, 2002). In China, if no soil erosion was occurring, various vegetative forms (such as seeds, spores, fruits, germinated roots and buds) might develop naturally, free from any external interference. In our demonstration area, degenerated vegetation was restored to the 1960s level after only three years of fencing (Jiang et al., 2003). The pioneer species such as colonizing grasses provide soil stability and are the first to occupy the degraded areas, they are gradually replaced by herbaceous shrubs that offer plant community structure (Liu et al., 2004).

(3) In the course of improving degraded sandy grasslands, a model of 'land self-improvement' has been developed. The approach involves improving land-use efficiency on smaller areas by using modern technologies thereby increasing the living standards of local inhabitants. By reducing the amount of land being used for cultivation, more land is left to recuperate naturally. The approach is both simple and effective. Demonstration districts could be developed in areas where water and electricity supplies exist, and fertilizers, transportation and agro-nomic techniques are available. The rest of the degraded land would then be enclosed to prevent grazing and mowing thereby allowing the natural revival of the native vegetation. The next step is to upgrade these areas into nature reserves under administrative protection.

(4) The practice of planting solitary species such as poplar on natural meadow is detrimental to the revival of grassland. Natural ecological revival should be the most immediate, economic and effective approach involving the least risk. At present, in their struggle against sandstorms, people attempt to take advantage of natural forces but human interference in the ecosystem is not addressed comprehensively. Natural revival will not be successful without consideration of the original destructive factors involved in the ecosystem's decay. We note that there are many projects claiming ecological revival when in fact they are doing nothing more than manipulating or constructing an ecosystem.

(5) The restoration of degraded grasslands can result in increased hardship due to increased production costs. Funding therefore has to be invested to boost urban development in small cities and towns. Funds should be used to solve various practical issues such as water and electricity supply, telecommunication networks, transport systems, educational infrastructure, and generally improving the living standards of local residents. Currently there is funding available for returning the original vegetation to reclaimed farmland, but there are few incentives for grass planting. If this policy is continued, grassland depletion will be aggravated further. By transforming the existing pattern of inter-related interests and land-use, local residents can take the initiative offered by ecological restoration and turn themselves from being consumers of nature to being its protectors.

(6) Large-scale grassland restoration must involve 'spatially heterogeneous' integrated management. That is, much of the land should be left alone for natural recovery and improved management schemes; delayed grazing or rotational grazing should be recommended. Principles in landscape ecology seem quite relevant in designing such spatial management plans.

(7) Sustainable strategies for grassland restoration and management must explicitly integrate ecological, economic, and societal issues in the overall framework. There is a great need to educate the local people and policy-makers as most of the grasslands can be restored with ecological and economic success if proper measures are rigorously implemented. The participation of local governments and herdsmen is of vital importance. On the one hand, a model of 'nurturing the land by the land itself' needs to be adopted; on the other hand, land-use practices must be diversified and optimized with the aid of scientific knowledge and advanced technological means so as to improve the economic and living conditions of the local people.

(8) The relationship between society and nature in the Inner Mongolia grassland has changed in response to the changing environment. There is little doubt that it will continue to change as everywhere else in the world. The real question is, how can

we make this dynamic relationship sustainable? To achieve environmental and economic sustainability while preserving the essential elements of the Mongolian culture in the region we believe that future research and management efforts should embrace the tenets of sustainability science (Kates et al., 2001; Wu and Hobbs, 2002), which is an emerging transdisciplinary field that focuses on the dynamic interactions between society and nature. Our experience in Hunshandake Sandland of Inner Mongolia grasslands suggests that such a new scientific framework is crucial for successfully resolving the problems of grassland degradation and dust storms.

(9) Providing opportunities of survival for the local Mongolian people should be seriously considered. Among all the methods, chicken faming might be a clever way. In inland China, intensive chicken farming in limited spaces helps spread avian flu that endangers food safety and public health, and invites criticism of China's animal-welfare issues. The wide-open spaces poultry need are not found in farmyards, much less in wire cages; the space is out on the grasslands. Chickens present no danger to the grassland and can help control pests. In the future, the huge quantities of chicken and eggs that China needs could come from the grasslands. The Chinese government should look to examine the idea of moving livestock southwards and chickens northwards. Model projects should be established in the south and the north using technology and the market to promote China's economic growth and sustainable development.

9. National seminars

1. During 16–17 September of 2004, a national seminar was held in Zhenlan Banner of Hunshandake Sandland area. Members who attended the workshop involved the following persons: ten persons of the project team from the Institute of Botany, the Chinese Academy of Sciences, Institute of Zoology, the Chinese Academy of Sciences, School of Environmental Science, Peking University, MAB National Committee for China, Institute of Mongolia Studies, Inner Monogolia University, Department of Sand Treatment, Inner Mongolia Agriculture University; eighteen persons from the local government and local village and towns, including four leaders from Zhenglan Banner (Ms. Li Shaofeng, Head of the Banner, Mr Li Yonggeng, Vice-Head, Mr Xi Zhinong, Vice-Head, Mr. Ai Baosheng, Director of Zhanglan Forestry Bureau); nine persons from the three towns (Shangdu Gele, Sanggen Dalai and Habi Riga); and five local herdsmen of Bayinhushu Gacha. We also invited three experts (Professor Chen Zuozhong of the Chinese Academy of Science, Professor Liu Shuyun of Inner Mongolia Normal University, and Professor Liu Shurun of Inner Mongolia University) for their comments and suggestions.

Some of the questions discussed at the workshop include: can the establishment of a biosphere reserve in Hunshandake Sandland help in the restoration of degraded grassland? What are the alternative means of survival for the people moved from the core area of the biosphere reserve? How can the local people be helped to increase the value of their animal products? Are water resources available for the forbs or weeds growing artificially?

2. During 29–31 September 2005, a national seminar on the sustainable management of Hunshandake Sandland was held in Zhenglan Banner of Hunshandak Sandland area, which involved the Zhenglan Banner Government, Xilin Gol League, and the project team from the Institute of Botany, the Chinese Academy of Sciences, MAB National Committee for China, Institute of Zoology, the Chinese Academy of Sciences, School of Environmental Science, Peking University, Institute of Mongolia Studies,

Inner Monogolia University, Department of Sand Treatment, and Inner Mongolia Agriculture University. The aim of the seminar was to identify natural restoration, and offer alternatives to government tree-planting schemes for discussion at workshops. Officials from the Ministry of Forestry, Ministry of Agriculture and the State of Environmental Protection Agency of the People's Republic of China were invited to attend the workshop. Furthermore, to address the importance of the demonstration effects of the SUMAMAD project, especially the remarkable efforts and results obtained by the Chinese Academy of Sciences, journalists from CCTV (China Central Television) and some important newspapers like the *People's Daily* were also invited. Some 35 persons attended the workshop.

3. During 31 August to 2 September, 2006, a national seminar was held in Zhenlan Banner of Hunshandake Sandland area. In the seminar, three officials from the Ministry of Agriculture of the People's Republic of China were invited. Participants include: Mr. Li Shumin, Head of Rear Livestock Division; Mr. Zongjinyao, Director of the Monitoring Centre of Grassland of China; Mr. He Ping, Head of Grassland Division; twelve persons from the local government and local village and towns, including four leaders from Zhenglan Banner (Mr. Ting Bater, Head of the Banner; Mr Hasi Bagen, Vice-Head; Mr Xi Zhinong, Vice-Head; Mr. Ai Baosheng, Director of Zhanglan Forestry Bureau). The rest of the delegation was composed of ten persons of the project team from the Institute of Botany, the Chinese Academy of Sciences, Institute of Zoology, the Chinese Academy of Sciences, School of Environmental Science, Peking University, MAB National Committee for China, Institute of Mongolia Studies, Inner Mongolia University, Department of Sand Treatment, and Inner Mongolia Agriculture University. Some of the questions discussed at the workshop include: can the model using natural processes be applicable in the restoration of other degraded grassland of China? How can respect of the Mongolian way of life and cultural tradition be maintained with the shift in land-use pattern (such as chicken farming)? What is the possibility of ecotourism in releasing grazing pressure in the steppe areas)? What are the national policies on the sustainable management of steppes, national ecological barriers or stockbreeding base? What are the potential ecological benefits among the ecological fragile areas through tree planting or grass seeding?

10. Research institution and team composition

10.1 Research institution

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Mr. Li Gang, doctoral candidate of the Institute of Botany, the Chinese Academy of Sciences.

11. Publications as a result of SUMAMAD

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2 Heihe River Basin

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1. Main dryland challenges at the project site

Situated deep in the hinterland of Eurasia, Heihe River Basin, including the Hexi Corridor in Gansu Province and the Ejina Banner in Alxa League of Inner Mongolia, is one of the driest areas in the world. The runoff generating area of the river basin, the Qilianshan Mountains, is small compared to the entire river basin. The extensive exploitation of the water and land resources in the upper and middle reaches of the basin over the past decades has lead to a sharp decrease in water resources in the lower reaches. This has resulted in severe deterioration of the ecological environment in Ejina Oasis, which is located in the lower reaches of the basin. As a result, the most crucial problem in Heihe River Basin is water-use competition between the upper, middle and lower reaches. Water shortage is caused by the rapid population growth and expansion of the irrigated land in the middle river basin. Consequently, the man-made oases in the middle reaches are expanding, while the natural oasis in the lower reaches is shrinking and degrading. Moreover, although water is scarce, wastage rates are still huge in most Irrigation Districts of the middle river basin.

2. Environmental characteristics of the study site

Inland river basins make up one-third of the total area in China, and with such naturally limited water resources combined with over-utilization, this has led to water becoming a critical issue affecting socio-economic development and ecological protection. With Heihe River Basin (HRB) as a case study, our project aimed to improve water use efficiency (WUE) at the river basin scale.

The Heihe River Basin is the second largest inland river basin in the arid region of northwest China. Its geographical location is between 96°42'E and 102°00'E longitude and 37°41'N and 42°42'N latitude. It covers an area of approximately 128,000 km^2, of which 57, 34 and 9% are Gobi desert, mountain, and oasis respectively. The mountains are runoff producing areas; oasis comes into being when sufficient runoff flows out of mountains and recharges basins; whereas in the Gobi, desert conditions appear when water is scarce.

The Heihe River originates in Qilianshan Mountains and passes through three provinces, which are Qinghai province, Gansu province and Inner Mongolia Autonomous Region. The river does not flow into the sea but ends in two terminal lakes in the desert. From the south to the north of the basin, there are three major topographic landscapes; the southern Qilianshan Mountains, the

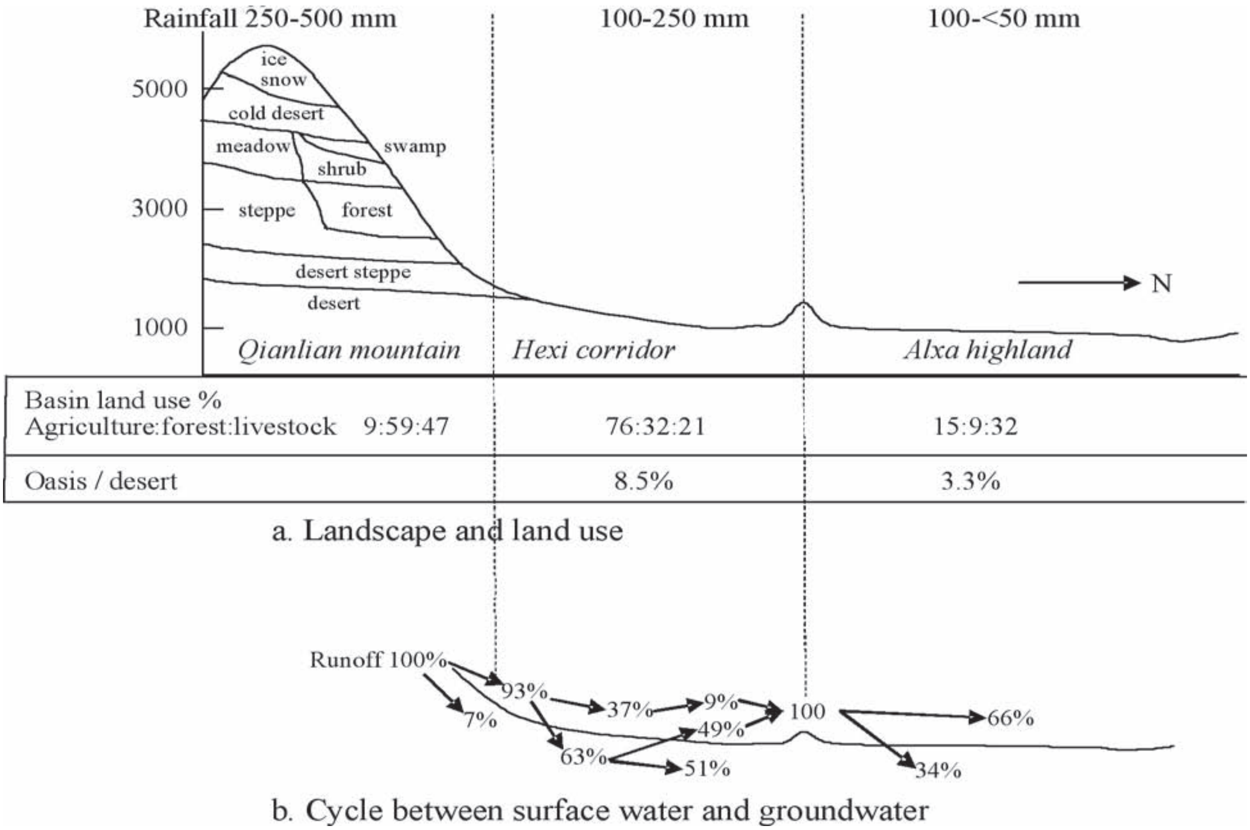

Figure 1. Soil, water and land utilization in the Heihe River Basin.

middle Hexi Corridor, and the northern Alxa Highland (Figure 1a).

The Qilianshan Mountains are the water source areas. The highest elevation is 5,584 m and the land above 4,500 m is covered by ice and snow all year around. Between 4,000 to 4,500 m, vegetation is sparse mat-grass and the annual precipitation is more than 400–500 mm. Restricted by low temperature, the landscape in this elevation is considered a cold desert. Between 3,300 and 4,000 m, there is an alpine meadow on the south-facing slope, with alpine shrub meadow and meadow swamp on the north-facing slope, of which 3,600 m is the lower limit of permafrost. From 2,700 to 3,300 m, the annual precipitation is 350–500 mm and the landscape is forest and grassland, which plays an important role in holding water in the basin. In the low to middle areas of the mountain with elevations between 1,900–2,700 m, the annual precipitation falls to 250–350 mm and the landscape changes from dry grassland in the lower area to desert grassland in the higher area. In the area below 1,900 m, there are low mountains and hills with annual average precipitation of 200–250 mm and landscapes of hilly desert or grassland desert.

The Hexi Corridor in the middle river basin is situated between the southern Qilianshan Mountains and the northern Beishan Mountain. It stretches 40–60 km from the south to the north. The tributaries originate from the southern Qilianshan Mountains and, depending on the topographic and geological conditions, discharge from east to west and finally enter into Damaying Basin, Shandan Basin, Zhangye Basin, East and West Jiuquan Basin, respectively. Desert oases exist in these basins. The corridor plain in the middle river basin is the centre of human activities with 90% of the available arable land in the whole basin.

The Alxa Highland located in the lower river basin is around 1,000 metres above sea level. Climate is extremely dry with annual precipitation of less than 50 mm and annual potential evapotranspiration of more than 3,500 mm. There are large areas with sparsely distributed population and extensive desert dotted with scattered vegetation. The biomass production of grassland is very low. Sandstorms, drought and salinity are prominent problems and the oasis only appears in the area near streams, rivers, lakes, irrigation channels and the area with shallow groundwater. The major feature of the land is its heterogeneity. The land from east to west could explicitly be classified into three categories: the Badain Jaran Desert in the east; alluvial and diluvium Gobi in the middle; and low mountain, hill and eroded plain in the west.

3. Socio-economic characteristics of the study site

Administratively, the upper reaches of Heihe River Basin include most of Qilian County in Qinghai Province and part of Sunan County in Gansu Province. In the Qilian County several ethnic groups (i.e. Han, Hui and Tibetan) live together and share the same land. It covers an area of 14,000 km^2, with the total population of around 30,000. The livestock number is 660,000. Animal husbandry is the predominant economic production system. The Sunan County is a Yugu ethnic group autonomous county. The total population is 15,000 and the total arable land is 2,900 ha, of which 1,200 ha are irrigated lands. In general, the level of economic development in the upper river basin is relatively low and the major economic production is animal husbandry.

The middle river basin includes seven counties and cities in Gansu Province. This area has a long history of agricultural production and still follows traditional irrigation practice. With a population of 1,212,000, this area has nearly 90% of the total population of the entire river basin. Irrigated farmland covers 223,000 ha of its total arable land of 261,000 ha. Major crops are wheat, maize, sunflower and sugar beet. The annual average grain production is 992,900 tons with grain per capita of 819 kg.

The lower river basin is a fragile area of desertified grassland. It includes Jinta County in Gansu Province and Ejina Banner in Alxa League of Inner Mongolia. Up to the beginning of the last century, the Mongolian tribes in Ejina lived as nomads. In the desert region, the main resource was livestock. Later, through governmental directives, the nomadic life was transformed to a sedentary life and agriculture and breeding began to develop. In 1999, there was a population of 66,300, and arable land of approximately 10,000 ha in the lower river basin.

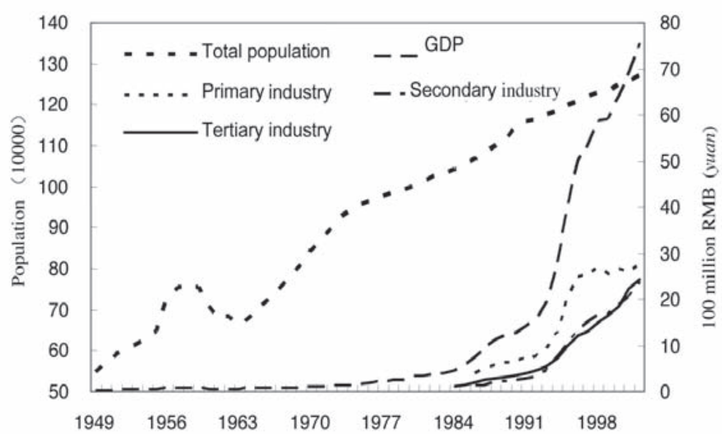

Figure 2. Population increase and industry development in the last 50 years in Zhangye County/City.

Because of the relatively abundant water resources (annual average water resources is 4.173 billion m^3), the Heihe River Basin is an important commodity grain base in northwest China. It has experienced rapid socio-economic development and drastic population growth (Figure 2). In 2000, GDP in Heihe River Basin was 11.027 billion yuan, with GDP per capita of RMB 5,687 yuan. It was the highest level in Gansu Province, but was still only 80.35% of the national GDP average per capita of RMB 7,078 yuan. Of the total GDP in Heihe River Basin, 3,905 million yuan comes from primary industry, 4,138 million yuan from secondary industry and 3,215 million yuan from the tertiary industry, in the following proportions of 35.41%, 37.53% and 29.16%, respectively.

4. Conservation of natural resources, community development and scientific information

4.1 Problems of water and soil development

The annual average water resources in Heihe River Basin is 4.173 billion m^3. Because there is a large and regular exchange between groundwater and surface water, it is possible to reuse water resources several times (Figure 1b), and the water utilization ratio (i.e. the ratio between developed surface water and total available surface water) in Heihe River Basin exceeds 112%.

The total water consumption in Heihe River Basin in 1998 was 3.433 billion m^3, of which agricultural water consumption was 2.986 billion m^3; forest, animal husbandry and fishery water consumption was 0.227 billion m^3; urban industrial water consumption was 0.1564 billion m^3; rural industrial water consumption was 0.0125 billion m^3; urban domestic water consumption was 0.0228 billion m^3; and rural domestic water consumption was 0.0288 billion m^3. Agriculture water consumption is therefore 87% of the total water consumption.

The most crucial problem in an inland river basin is the water-use competition between the upper, middle and lower reaches. In the Heihe River Basin, because the three provinces have great differences in their economic structure and water use practice, there are serious water conflicts and complicated benefit-sharing. Water shortage in the lower reaches has been augmented by the rapid economic development, urbanization and expansion of areas irrigated in the middle reaches. With 90% of the total irrigated land and over 85% of the total population, the middle reaches of the Heihe River Basin consume 68.1% of the total water demand. However, while water is scarce, wastage rates are still huge in most Irrigation Districts. Canals are the main method for transferring water; flood irrigation is predominant and more efficient irrigation systems such as sprinklers and drip irrigation is rarely used. Irrigation water is charged according to the area of farmers' field plots rather than the volume of water usage so there is no incentive for farmers to save water. The average irrigation quota of 10,000 m^3 per hectare is 40% higher than that of the country; and the average water consumption of 1,736 m^3 per 10,000 yuan GDP is 1.85 times greater than that of the entire country.

Moreover, river discharge to the lower reaches has reduced dramatically since the 1980s due to the expansion of manmade oases in the middle reaches. The discharge flowing into Ejina oasis was more than 500 ~ 600 $Mm^3 yr^{-1}$ before the 1990s. But it was to reduced to 300 ~ 400 $Mm^3 yr^{-1}$ in the 1990s because of the increased water diversion in the middle river basin. Consequently, the Heihe River in Ejina Banner has been drying up for most of the year, and the two terminal lakes, the West Juyan Lake and the East Juyan Lake, dried up in 1961 and in the early 1990s, respectively. The groundwater table has fallen and water quality has deteriorated due to the reduced surface discharge.

4.2 Degradation of the ecological environment

Human activities have significantly changed the distribution and allocation of the limited water resources in Heihe River Basin, leading to a contradiction between desertification and expansion of the oases. The manmade oases in the middle reaches are expanding, while the natural oasis in the lower reaches is shrinking and degrading. The reduction of the water flow downstream led to a series of environmental problems, such as the drying up of tributaries and terminal lakes, shrinking of natural oasis, loss of biodiversity, secondary salinity and land desertification. Compared to the 1980s, the natural forest has reduced by 343 km^2, degraded grassland has increased by 3,948 km^2, desertified land has expanded by 405 km^2, and saline land has increased by 835 km^2. The dried-up river course and the terminal lakes have become the main sources of sandstorms (Figure 3).

Figure 3. Desertification in the surrounding areas of the terminal lake.

In addition, grassland in the upper reaches has degraded dramatically due to livestock over-grazing. Around 30% of the total land in Sunan County became desertified land in 2000. The area of natural forest has been reduced by 16.5% owing to the tree-cutting and irrational cultivation during the 1950s–1970s. Consequently, soil water holding capacity has reduced substantially and the loose, dusty soils have become susceptible to water erosion.

4.3 Community development

Today the economy in Heihe River Basin is quite contrasted. While large-scale Irrigation Districts have developed in the middle river basin and produces 35% of food in Gansu Province, in the rural farms in both upper and lower river basin, families are comparatively isolated and follow natural cycles and ancient traditions. The two economies are connected and interdependent; both have forced and continue to force the natural evolution of the ecosystem, both have to look for the right way to produce that ensures the sustainable development of the entire river basin.

Agricultural communities in the middle river basin are facing a declining water supply because annual water consumption is limited by the Master Plan of the Heihe River Basin. Pumping groundwater for irrigation not only increased the cost of agriculture but also resulted in a drop in the groundwater table.

The communities in the upper and lower reaches, where several different ethnic groups live together, rely on sheep and goat breeding as the major sources of income. The environmental degradation in these areas highlights the necessity to produce fodder for livestock. However, due to a lack of funding and technology, the communities conduct poor agricultural practices, which have allowed widespread agriculture to replace natural vegetation. Unfortunately, this exposes bare soils when fields are fallow and results in degraded land where agriculture can no longer be sustained.

4.4 Government actions

Central government has been concerned with the issues arising in the inland river basin and has been looking for an integrated river management strategy to combat the problems. A basin-wide management organization was then set up and a Master Plan of the Heihe River Basin aimed to discharge adequate environmental flow to the lower reaches, which was initiated in 1992 and revised in 1997 and 2000.

The Heihe River Basin Administrative Bureau (HRBAB) was set up in January 2000 and is responsible for water resources management and coordination in the basin. However, as previously mentioned, the issues in this river are quite contrasted because the river flows across three provinces that have great differences in terms of their economic structure and water use practices (i.e. grazing livestock in the upper river basin, irrigated agriculture in the middle basin, and small farm and livestock production in the lower basin). Water conflicts and benefit-sharing exist among these areas. Currently, the capability and authority of the HRBAB still needs to be improved and strengthened.

In August 2001, the State Council officially ratified a Master Plan of the Heihe River Basin (MPHRB) aimed at achieving this goal in five years such that the lower reaches receive 950 Mm^3 yr^{-1} of discharge when the water discharge at Yingluoxia Dam reaches 1,580 Mm^3 yr^{-1}. Through the efforts of HRBAB and local governments over the past five years, the MPHRB target has generally been achieved. As a consequence, the degradation of the ecological environment in the lower river basin has to some extent been mitigated. However, due to the implementation of the MPHRB, water withdrawal in the middle river basin had to be reduced by 23% of its prior usage, which resulted in water stress of approximately 40,000 ha of cropland in 2002. Farmers in the middle river basin then started to pump groundwater for irrigation and there was recent evidence of a drop in the groundwater table. These phenomena complicated the problems of water allocation and environmental water requirements.

The complicated problems in the inland river basin could not be solved solely through government intervention and by focusing only on water issues. Therefore, an integrated project that incorporates water activities and ecological and economic issues at a river basin scale was implemented in the Heihe River Basin led by the Institute for Cold and Arid Regions Environmental & Engineering Research (CAREERI), and in association with local governments and communities.

5. Practices implemented for soil and water conservation

5.1 In the upper river basin

The major objectives in this area were to improve the water holding capacity of the mountain areas and to rehabilitate the degraded grassland (Figure 4). Activities were carried out as follows:

- Completion of reconnaissance of the current status of the grassland and livestock resources in the region.
- Identification and demonstration of key techniques to rehabilitate the degraded grassland, including improvement of grassland vegetation communities (i.e. mixture of annual gramineous grass and legumes), aerial sowing, fencing, fertilizer application, and weed and pest control measures.
- Deferred grazing was demonstrated in order to release grazing pressure in the fragile grassland. Plants grow slowly in the early spring, if grazing is allowed during this time of year the plant never gets a chance to grow. Deferred grazing keeps livestock in pens during the beginning of the plants' growing season, and allows grazing in summer.

- An integrated monitoring system was established to study the water dynamics in soil-plant-atmosphere continuum.

Figure 4. The Qilianshan Mountains in the upper river basin are the water sources areas.

5.2 In the middle river basin

Intensive water-saving measures were demonstrated in the middle reaches to improve water use efficiency (WUE).

In the past, attention has focused on technical demonstrations aimed at increased yield; water-saving measures tend to promote technological solutions rather than technologies and practices appropriate for low-income farmers. Our project has worked closely with local governments and communities to develop and demonstrate practical water-saving measures using systematic and integrated approaches.

A field of 200 ha in Pinchuan Irrigation District of Linze County was selected as a demonstration site to conduct integrated water-saving activities.

5.2.1 Improve water use efficiency of flood irrigation

Flood irrigation was and will continue to be the main irrigation method in Heihe River Basin. Although it has low costs of adoption, the flood irrigation was relatively inefficient with water use. Demonstrations were carried out to improve water use efficiency through canal lining, land leveling and irrigation scheduling. For example, a flood irrigation plot usually measures 1–2 *mu* (*mu* is a Chinese unit for area; one mu is one fifteenth of a hectare). Our research experiment found that around 10% of water could be saved through simply reducing the size of the flood irrigation plot to 0.5 *mu*.

5.2.2 Crop structure adjustment

The objective of changing crop structure was to re-allocate water towards higher priority uses. A new variety of maize was introduced in the project. Although the yield of new variety (7,125 kg ha^{-1}) was lower than common maize (10,701 kg ha^{-1}), it had a much higher market price (i.e. 0.25 USD kg^{-1} compared with 0.11 USD kg^{-1} for common maize) because it could produce good quality maize seed. Therefore, the water productivity, which means economic return per cubic meter of water, was 0.11 USD m^{-3} for common maize, and 0.17 USD m^{-3} for the new variety (Table 1). Because the new variety has higher water productivity, its growing area increased five times compared to 1990 with 85% and 50% reduction of the common maize and wheat, respectively.

Maize Variety	Yield (kg ha^{-1})	Price (USD kg^{-1})	Irrigation Water (m^3 ha^{-1})	Water Productivity (USD m^{-3})
Common maize	1,0701	0.11	1,0275	0.11
New variety	7,125	0.25	1,0275	0.17

Table 1. Water productivity comparison between the common maize and the introduced new variety.

5.2.3 Improve irrigation management

Currently, the water price system provides no incentive for farmers to save water because irrigation water is charged according to the area of farmers' field plots rather than the volume of water used. To clarify water entitlement for individual farmers, water-rights cards and water tickets were introduced in Pinchuan Irrigation District as symbols of water use rights. On a water-rights card, the effective irrigated area is identified and classified into several categories. Based on the measured irrigated areas and quotas, the total water demand for the individual farmer is specified on the water-rights card. Farmers can apply for water tickets after they obtain the water-rights cards. Water tickets are issued in accordance with the amount of water that water users are entitled to in a particular year on the basis of their water rights. When the farmers want to irrigate, they need to show their water-rights cards and the corresponding amount of water tickets.

5.2.4 Community participation

The state-controlled type of organizations in China usually manage Irrigation Districts (IDs). In recent years, development strategies have changed dramatically with emphasis towards a shift from the central control towards greater participation by local government or non-government organizations. In the Heihe River Basin in 2001, Water Users Associations (WUAs) were introduced. A transfer agreement covering irrigation operation and maintenance (O&M) was signed between Irrigation Districts and WUAs. The responsibility of the WUAs includes the operation and maintenance of the tertiary canal and laterals; the design of a water use plan; establishing contracts between water users and relevant agencies; management of water-rights cards and water tickets, and the collection of water fees.

5.2.5 Shelter-belt construction

Besides agriculture, the second largest water consumer in an oasis is the shelter-belt system. Research was therefore focused on the adjustment of the shelter-belt structure, the adoption of species with low water requirements, and increase in the proportion of rainfed shrubs, and the protection and rehabilitation of the native species at the edge of the oasis. The ultimate purpose was to construct a shelter-belt with low water requirements and a high protection function (Figure 5).

Figure 5. This is a typical area in the transitional zone between desert and manmade oasis in the middle river basin. This area was covered by moving sand-dunes before it was developed. Native species were planted in the sand-dune in the early 1980s as shelter-belts. The farmland is one of our experimental fields to study the water use and environmental impacts of farming activities.

5.3 In the lower river basin

The practices in this area aimed to rehabilitate the ecological function of the desert riparian forest and maintain ecological security.

5.3.1 Fencing

Livestock overgrazing is one of the major factors that result in severe vegetation degradation. Funded by the local government, fences were erected in some key areas to relieve grazing pressure. We provided technical support to manage the enclosure area. For example, *Populus euphratica* is a major species in the area and has experienced drastic degradation. Practices such as seasonal irrigation, shallow cultivation to stimulate root growth, and plantation were demonstrated to recover the *Populus euphratica* forest.

5.3.2 Plantation

In the Gobi desert of Ejina Banner, native shrubs such as *Haloxylon ammodendron* have severely declined because of overgrazing and prolonged drought. Plantation was carried out in an area of 2,898 ha to demonstrate practical techniques. Moreover, *Cistanche deserticola*, a medicinal plant and locally known as desert ginseng, naturally relies on the root of *Haloxylon ammodendron* for growth. Techniques have been implemented to artificially plant the seed of the desert ginseng in the root of the *Haloxylon ammodendron* (Figure 6).

Figure 6. Plantation of the native species (*Haloxylon ammodendron*) and medicinal plant (*Cistanche deserticola*) harvest as new income alternatives.

5.3.3 Evaluation of the environmental water requirement

The Environmental Water Requirement (EWR) of the Ejina Oasis is the amount of water required to maintain the steady growth of the natural oasis and the manmade oasis protective system. The following activities were carried out within the framework of our project: we analysed the ecological evolution and changes caused by the impact of human activity over the past forty years; we identified criteria and methodologies for evaluating river basin ecological security; and we developed a model to predict EWR under different scenarios. The results of this study provide essential information and a theoretical basis for the effective design of integrated water resources management for the entire basin.

6. Income-generating activities initiated

6.1 Ecotourism in the lower river basin

While intensive water-saving measures have been carried out in the middle Heihe River Basin, development strategy in the lower river basin has focused on the rehabilitation of the degraded ecological environment. It is essential that the increased river discharge should remain in the stream as environmental flow and not used for water-consuming economic production such as further expansion of the irrigated areas. Therefore, many activities such as growth of cotton and *hami* melon, stall-feeding (see section 6.3) and ecotourism, have been trialed and demonstrated in this area as new income alternatives for local farmers and Mongolian herders.

The Eijina oasis has great potential for ecotourism. Thirty thousand hectares of poplar woods, *Populus euphratica*, an ancient wood species originating from Mediterranean

Figure 7. There is great potential ecotourism in the Ejina Oasis in the lower river basin: ancient plant species (*Poplar diversifolia*) and camel culture.

seashores about sixty million years ago, are still alive and in good condition along the Ejina river valley downstream of Heihe river (Figure 7). This is the largest part of three major distribution areas of poplar woods in the world. The local festival of golden autumn poplar is now an impressive event attracting many tourists, scientists and photographers.

The traditions of the local people are closely related to their Mongolian origins. Centuries-old camel breeding has merged into the daily life of nomadic Mongolian Heshuote and Tuerhute tribes, so that camel culture has reached a particular harmony. Camel herders live off camels using them as the only form of transportation; collecting its hair for sale; and fermenting camel milk to produce a popular drink.

6.2 Integrated 'mountain-valley-oasis' system

Traditionally, most people in the Heihe River Basin are engaged in three types of economic production, which are livestock grazing in mountain areas, small-scale agriculture in valley areas, and large-scale agriculture in the oases. These three areas are almost isolated with little communication. As a consequence, they rely heavily on their own natural cycles that overtime has resulted in grassland degradation in the mountain areas due to livestock over-grazing, farmer's low income in the valley areas owing to poor irrigation practices, and high water consumption in the large-scale oases. In order to integrate regional resources and maximize economic benefit, an integrated 'mountain-valley-oasis' system has been developed. It includes the coupling of the grazing livestock production in mountain areas, fodder production and stall-feeding in valley areas, and fodder growth and processing in oases (Figure 8). A communication mechanism was developed between these areas and they started to share resources. Private companies were established locally or introduced from outside. The companies signed contracts with stall-feeding households so as to reduce market risk.

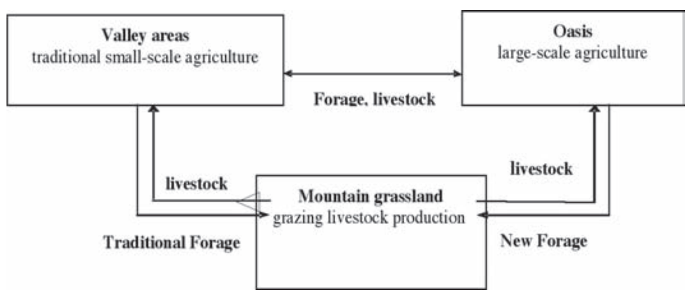

Figure 8. Integrated "Mountain – Valley – Oasis" System.

Figure 9. Stall-fed sheep. This highlights the need to provide balanced nutrition, which is essential for the success of stall feeding.

6.3 Stall-feeding

Livestock grazing was the main income for Mongolian tribes. When the nomadic way of life changed to a more sedentary one, grazing also changed to confined pasture (Figure 9). The environmental degradation related to local overgrazing highlighted the necessity to produce fodder for livestock and to keep animals in pens all year round or at least at certain times of the year. Stall-feeding was at the centre of the 'mountain-valley-oasis' system. Lambs for meat could be sold at three months old as 'baby lamb' or stall-fed until around six months old. Herders no longer kept large numbers of livestock and this reduced grazing pressure on the grasslands. Stall-feeding in the valley and oasis provided new alternatives for farmers to make profits and increase market demand for fodder, which in turn increased the growth of fodder crops such as alfalfa, which require less water than cereal crops.

7. Results obtained

7.1 Water savings

Intensive water-saving measures were trialed and demonstrated. The total water use efficiency in the demonstration site increased by 20-25% and water productivity doubled (Table 2). The annual average water consumption in Pinchuan Irrigation District decreased from 63 Mm^3 to 49 Mm^3.

7.2 Better irrigation management

The transfer of operation and maintenance responsibilities to farmers through the establishment of WUAs has provided some improvement in water delivery services, system maintenance, expansion of the area irrigated as well as reduce conflict among farmers. For instance, 114 WUAs in Lingze County completed 392 facility maintenance activities in 2003. In addition, collection of the water charge was generally improved because the water users (farmers) were satisfied of the quality of water delivery, and there was increased transparency of irrigation cost.

7.3 Ecological environment rehabilitation

In the upper river basin, the aboveground biomass production increased by 875 kg ha^{-1} in the grassland after three years of fencing. Therefore, the stocking rate of this grassland has improved substantially. Surface runoff was reduced and the soils were no longer susceptible to wind erosion due to the increase in vegetation coverage. In addition, through the implementation of

Water-saving measures	Increased water use efficiency
Improve flood irrigation	8–9%
Shelter-belt reconstruction	2–3%
Horticulture	1–2%
Water right cards and water tickets	4–5%
New maize variety	5–6%
Total	**20–25%**

Table 2. Water-saving measures demonstrated in Pinchuan Irrigation District of Linze County.

integrated measures such as fencing, aerial sowing, and the control of unpalatable plants, in three years the grassland in mountain areas could produce edible fresh grass of 2,515.5 kg ha^{-1}, almost double prior productivity.

In the middle river basin, it highlighted the buffering function of the transitional area between the desert and the edge of the man-made oasis. An area of 300 ha of shelter-belt was established in the transitional area in order to demonstrate its integrated wind protection function. This shelter-belt was composed of native species such as *Haloxylon ammodendron, Tamarix ramosissima, Hippophae, Haloxylon ammodendron* and *Caragana korshinski*.

In the lower river basin, an area of 1,000 ha was selected as a demonstration site to study environmental rehabilitation technologies in desert oasis. Results reveal that the vegetation coverage in fenced *Populus euphratica* forest increased by 10–20%; the survival rate of plantation (*Haloxylon ammodendron*) in the Gobi was as high as 75–80%.

7.4 Income-generation

With the substantial increase in grassland productivity in the enclosure area of the upper river basin, as mentioned earlier, economic benefits of animal husbandry in this area have improved resulting in more than a 50% reduction in the death rate of livestock in winter, and a 10% increase in the survival rate of young animals.

Stall-feeding and lamb-fatting were successfully demonstrated and has been widely extended by government directives. Seven hundred households throughout eighteen villages in Sunan County have begun to stall-feed animals (mostly sheep). The annual average income of the demonstration household has increased by RMB 300 yuan.

Figure 10. Water-saving training. Farmers were taken to the field to see the water-saving construction.

In collaboration with a local company, a factory with an annual capacity of 20,000 tones of alfalfa products was established in Linze County. This factory provided new employment opportunities for local people and good quality products for stall-feeding.

The lower river basin benefited from ecotourism and artificial plantation of the medicinal plant *Cistanche deserticola*, and household income in the demonstration site increased by 20%.

reports. Farmers and herders were involved as demonstration households. Technical guidance and training was provided to them on common applied techniques (Figure 10). In addition, our demonstration site in Linze has become a scientific base for students from middle schools and primary schools in Zhangye City to learn about science and technology.

7.5 Capacity building

This project has worked closely with local governments including Zhanye Region Government, Sunan County Government and Linze County Government in Gansu Province, and Ejina Banner Government in Inner Mongolia. The Water Resources Bureau and Agricultural Extension Station were key agencies in the implementation of the demonstration activities. Their technical staff was closely involved in the demonstrations, during which they received opportunities to participate in training and received recognition for research results and

7.6 Policy influence

The innovative experiences identified in this project can be sustained beyond the project thanks to the close collaboration with local governments and communities, and the emphasis on integrated approaches at the river basin scale coupled with water, ecological and economical issues. This integrated river management principle is appropriate for all inland river basins in northwest China. It is essential for solving the problems of water competition in the different administrative regions of a river basin. The results of this project provide essential information and practical solutions for the effective management of inland river basins in northwest China. In 2007, a new project was approved and we are going to apply the experiences and practices learned in Heihe River Basin to Shiyanghe River Basin, which is another inland river basin in China.

8. Recommendations for sustainable dryland management

- The issues stated above in northwest China serve as a warning; only if the issues are studied at the basin scale, commencing with an integrated river management system that oversees coordination between water, ecology and economics, can there be sustainable development in the region.
- For the integration of water, in ecological and economical planning, one critical principle to adopt is an action plan according to the availability of water,

which means economic development must consider the available water so as to decide on agricultural area and economic scope; vegetation recovery must consider the available water in order to identify the area and scale of plantation.

- Human beings are at the centre of society. While efforts have focused on the rehabilitation and protection of the degraded environment, income alternatives for local communities must be highlighted.
- Improvement of WUE includes integrated and complex processes. It is broader in scope than simply using agro-nomic and biological solutions and must consider the Irrigation District, watershed or river basin scale. At the Irrigation District scale, efforts should be taken to use every possible water-saving measure in whole-farm production.

9. National seminars

1. A training course on "The practical measures of ecological rehabilitation and the research of eco-hydrological evolution in Heihe River Basin" was provided on 25–27 April 2004 in Bayanhot, Alxa League of Inner Mongolia. Twenty-two people from relevant agencies (i.e. water resources bureau, agriculture and animal husbandry bureau, forest bureau, environmental protection bureau, grassland management station, *et. al.*) in both regional level and county level participated in the training course. Presentations were mainly given by Prof. Xiao Honglang. Discussions were carried out during the training course and a half day field trip was organized.

2. A national seminar was held on May 2004 in Zhangye City, which is the biggest city in Heihe River Basin and is located in the middle basin. The theme of the seminar was "Science and Development". Scientists and officials from the Department of Water Resources Management in Gansu Province, Heihe River Basin Administrative Bureau, Lanzhou Branches of Chinese Academy of Sciences and CAREERI discussed the water problems in Heihe River Basin; the current research status; the practices implemented for soil and water conservation and integrated river basin management strategies.

10. Research institution and team composition

10.1 Research institution

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CAREERI-CAS is a newly re-organized institute set up in June 1999 from three former institutes of the Chinese Academy of Sciences in Lanzhou: the Institute of Glaciology and Geocryology, the Institute of Desert Research, and the Institute of Plateau Atmospheric Physics. The new institute aims to achieve disciplinary integration and scientific synthesis based on the unique and specific disciplines it currently represents. There are now 350 full-time employees, of which 65 professors, in the new institute.

CAREERI has a view to integrate studies on the interaction mechanism and processes between the cryosphere, atmosphere, hydrosphere, biosphere, and pedosphere. It focuses mainly on three research fields, which are deserts, inland river basins and cryology. With these scientific capabilities, the institute can respond adequately to the requirements of national objectives in the development of Western China, and can provide fundamental theory and key technology for the rational development and utilization of land and natural resources, environmental protection and ecological construction in the region.

Substantial and significant achievements have been acquired over the past forty years. Over 1,000 projects were implemented by the institute, of which more than 500 projects obtained great results. The institute has won 150 rewards at both state and local levels. Of all the awards, one received the top grade, three received the first grade of the State Scientific and Technical Progress Award, and one received the first grade of the National Natural Scientific Progress Award.

The Division of Water-Land Resources, one of CAREERI's eight research divisions, has a laboratory for hydrology and applied ecology as well as two field stations (i.e. Linze Water-Land Resource and Ecological Experiment Research Station, and Ejina Desert-Oasis Hydrology and Ecology Station). The main focus of this division is the study of the inland river basin involving research on geography, hydrology, eochydrology, ecology, pedology, environmental science, water-land resource and management, eco-economics, and river basin sustainability.

10.2 Team composition

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Team members

Our division has an excellent team – the Heihe River Basin Science Group. The group is composed of thirty-two people: Professor Cheng Guodong, academician of CAS, leads the group; the other twelve professors and their expertise are as follows: Dr. Xiao Honglang, river basin water management; Dr. Zhao Wenzhi, ecohydrology; Dr. Feng Qi, hydrology; Dr. Li Xinrong, ecology; Dr. Xu Zhongmin, eco-economics; Dr. Duan Zhenghu, pedology; Dr. He Yuanqing, glacial science; Dr. Wang Keli, climatology; Dr. Jin Helin, environmental change; Dr. Su Peixi, biology; Dr. Su Yongzhong, oasis agriculture; and Dr. Chen Rensheng, GIS. This group has PhD programs in physical geography, ecology, hydrology, pedology, water-land resource and so on. It is also a national base for postdoctoral training.

11. Publications

Cheng Guodong, Xiao Honglang, Zhao Wenzhi, *et al*. 2005. *Integrated management of the water-ecology-economy system in inland river basin of China: a case study of the Heihe River Basin*. Science Press, Beijing.

Cheng Guodong. 2002. Study on the sustainable development in Heihe river watershed from the view of ecological economics. *Journal of Glaciology and Geocryology*, 24 (4): 335–343.

Feng Qi, Cheng Guodong, Masao, M K. Trends of water resource development and utilization in arid north-west China. *Environment Geology*, 2000, 39(8): 831–838.

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3 Omayed Biosphere Reserve

Egypt

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1. Main dryland challenges at the project site

The western coastal desert of Egypt and its hinterland is renowned for its wealth of natural resources and has thus been attractive for development projects as well as for its fine location, good weather, and pleasant conditions. Except for the coastal strip, most of the north-western desert is situated in an arid region. Water resources are scarce and variable in this region and as a result the local community has developed a wide range of strategies for managing water resources. Depending on rainfall pattern, they traditionally move to seek out water, pasture and croplands. However, following sedentarization and such political and social forces as population growth, the overuse of water resources, climate change, and overgrazing and uprooting of indigenous vegetation, the pressure on land resources has increased which invariably has affected society's performance and the provision of goods and services. There is therefore an urgent call for the development of an integrated management system for these drylands. The principal aim is to somehow enhance the rational use of natural resources while improving the well being of the local inhabitants without degrading this fragile environment.

In the last few years, the area has also witnessed stresses on water resources that have led to undesirable consequences related to both its quantity and quality. Recently established summer tourism resorts along the coastal area have damaged the important freshwater aquifer (dune sand accumulation) near the coast. In addition, groundwater pollution either by salt-water intrusion or by sewage from septic tanks or landfills (from the resorts) has been noticed in some areas. With regard to land, the desert ecosystems are exposed to both natural and human induced impacts. Examples of the former include aridity and soil surface erosion; the latter include overgrazing, woodcutting, soil salinization, and the introduction or expansion of agro-forestry systems with multiple land-use to develop tourism, wildlife, hunting and sports. These impacts either act in isolation or in combination with each other. Rangelands in particular provide services that are renewable, thus they are capable of providing continuous goods and services such as forage, fibre, meat, water, and recreation areas. These resources are considered by many people to be an integral part of their traditional heritage, which adds importance to their value. Concomitantly, due to pressures from overgrazing, the uprooting of plants, and off-route use by vehicles, rangelands are now in poor condition; they have either been altered or destroyed. The result is an almost complete removal of vegetation cover, an intensification of the desertification process, and the destruction of wildlife habitats. Rangeland degradation has resulted in the disappearance of perennial grasses which in turn has intensified the periods of pasture shortage; the more palatable shrubs, perennial grasses and legumes have been replaced by less palatable plants.

1.1 Main environmental constraints

Moghra oasis occurs in the hinterland of the Omayed area in the north-western coastal region of Egypt where Omayed Biosphere Reserve (OBR) is situated. It is considered one of the most important Egyptian inland water bodies. Its importance stems from the dependence by the local inhabitants on this area as an alternative rangeland during the dry season where the water resources support dense vegetation cover and thus increases the grazing capacity of Moghra's rangeland. In time of natural forage shortage, herds from the Omayed region move to Moghra so as to benefit from its rangelands placing the region under growing pressure from overuse and resource exploitation, especially in terms of the vegetation cover.

Moghra oasis has received little attention in terms of the study and evaluation of its natural resources. Although Moghra resources remain pristine, with high productivity of its natural vegetation particularly in the salt marshes around the lake, it is considered to be a very fragile ecosystem and it is certainly prone to degradation. Moreover the irreversibility of human pressure exceeds the limits of tolerance. Moghra oasis is subjected to a number of environmental threats. The main threats on the habitats occur from grazing pressure exerted on the vegetation cover in the oasis; local communities from the coastal area bring their stocks of camels, sheep and goats to graze here every year from May to October. Moreover, there is a proposed project to reclaim some areas near the oasis and to establish some desert resorts that would destroy the natural habitats, alter the species composition, and pollute the area (Figure 1). An additional threat is the continued natural drying of the area (perhaps induced by global warming), which may lead to the complete loss of wetland habitats and their replacement with salt flats and sand areas similar to those commonly seen in the Sahara.

The area is subjected to acute environmental conditions making it unsuitable for agriculture. However, this area may be suitable for grazing and groundwater observations (Figure 2). It is hoped that results obtained from this project could be used to link Moghra Oasis to

Figure 1. Location of the proposed project activities in and around Moghra Oasis.

Figure 2. Recent agricultural activities in Moghra Oasis.

Omayed Biosphere Reserve (OBR), which is situated at the northern coast and inland to Moghra Oasis. Moghra Oasis could serve as an additional core area linked to OBR by an ecological corridor or a satellite protected area on its own.

2. Environmental characteristics of the study site

The SUMAMAD project activities were implemented in OBR. It was suggested by the Egyptian team that the hinterland of the OBR be included in the study site as it is socially, culturally and ecologically linked to OBR. The hinterland covers the southern land of the Omayed area in the north-western coastal desert of Egypt, and extends southwards towards Moghra depression. Details of the OBR site and its physical and biological characteristics are described below:

2.1 Location

Omayed Biosphere Reserve is located in the western Mediterranean coastal region of Egypt (29° 00' – 29° 18' E and 30° 52' – 30° 38' N). It extends about 30 km along the Mediterranean coast from west El-Hammam to El-Alamin with a width of about 23.5 km to the south (Figure 3).

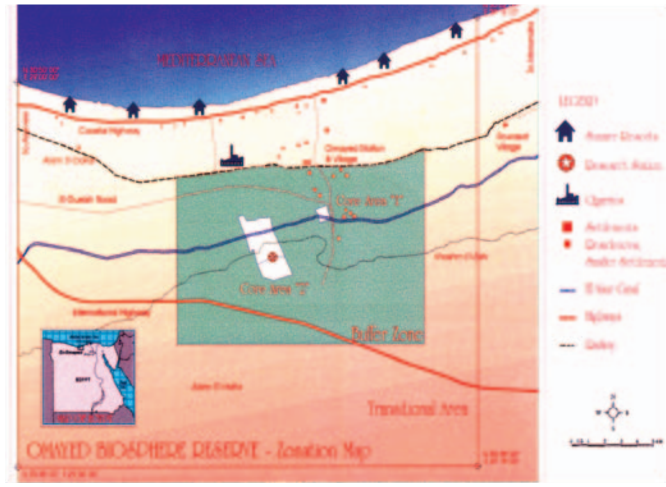

Figure 3. Location of OBR.

Its N-S landscape is differentiated into a northern coastal plain and a southern inland plateau. The coastal plain is characterized by alternating ridges and depressions running parallel to the coast in an E-W direction. This physiographic variation distinguishes six main ecosystem types. They are arranged in sequence from the northern Mediterranean coast to the south as follows: 1) Coastal ridge composed mainly of snow-white oolitic calcareous rocks, and overlain by dunes; 2) Saline depressions with brackish water and saline calcareous deposits (i.e. salt marshes) – in other places, the depressions are less saline and the water table is deep (>1m); and 3) Non-saline depressions with a mixture of calcareous and siliceous deposits of deep loess. Rainfed farms are a pronounced manmade habitat within the non-saline depressions in this region.

2.2 Study area

Moghra Oasis is one of two oases (Moghra and Qara) in the Qattara Depression, which are the largest depressions in the Egyptian desert. The area of this depression covers about 19,500 km^2 below sea level with a maximum depth of -133 m (Giris *et al*., 1971; Hughes and Hughes, 1992; Zahran & Willis, 1992). Moghra Oasis is a small uninhabited oasis (Lat. 30° 14' N, Long. 28° 55' E) situated on the north eastern edge of Qattara Depression and centered by a brackish-water lake (Figure 4). The lake is about 4 km^2 including a *Phragmites* swamp. There are salt marshes on the boundaries, which are encroached by wind blown sands in some areas. The lake comprises the lowest part in the oasis (-38 m), as displayed in the digital elevation model. In Moghra, the Moghra formation, named by Said (1962) represents the Lower Miocene clastic sediments forming the northern cliffs of the Qattara Depression. The Moghra formation also occupies most of the floor of the Qattara Depression, which is made up of sandy and clayey layers of the Lower Miocene. The maximum thickness of the Moghra aquifer is about 930 m in the northeastern part. Along the Mediterranean Sea, the aquifer's thickness decreases sharply to zero where it gradually turns into an impervious, clayey facies. The Moghra aquifer is recharged from five different sources: 1) direct rainfall on the aquifer's outcrops; 2) groundwater seepage from the overlying Marmarica limestone aquifer; 3) the Mediterranean Sea; 4) the Nile Delta aquifer; and 5) upward leakage from the Nubian artesian aquifer (Rizk and Davis, 1991).

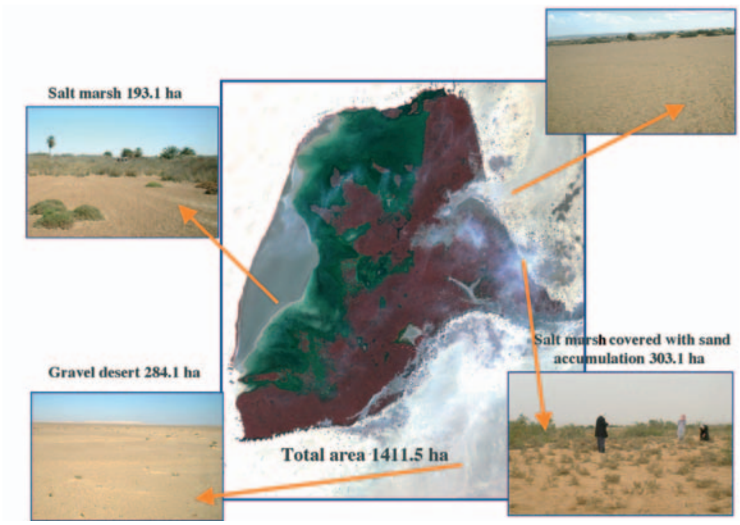

Figure 4. Location of Moghra on a satellite image (Landsat-TM) showing the major habitats of Moghra oasis.

2.3 Climate

The Omayed area represents a 'sub-desertic warm temperate climate' (UNESCO, 1977). The rainy season begins during the second half of October and extends to the first half of May. About three quarters of the total amount of rainfall occurs during November through to February. December and January are the rainiest months, although some showers may still occur in March whereas spring is virtually dry receiving only about 10% of the total rainfall. The average temperature of the warmest month is 30.8°C, and the average temperature of the coolest month is 7.9°C. Mean annual precipitation is 120 mm, recorded at an elevation of 10 metres. The ratio of annual precipitation to annual evaporation is between 0.03 and 0.2 (UNESCO, 1977). The comparison of meteorological records in two stations indicates the increase in environmental aridity and thermal continentality from the north to the south.

2.4 Geology

The geological formations of the region are essentially Quaternary and Tertiary. The surface is formed of Miocene strata, about 300 m in thickness, overlain by pink limestone and tentatively assigned to Pliocene. The Holocene formation is formed of beach deposits, sand dune accumulations, wadi fillings, loamy deposits, lagoonal deposits, and limestone crust. The Pleistocene formation is formed of white limestone in the form of exposed ridges stretching parallel to the coast, and pink limestone of oolitic sand with Pleistocene microfauna.

2.5 Vegetation characteristics

A total of 24 field visits were conducted in order to survey the natural plant resources of Moghra Oasis, assess their sustainable uses, and provide a basis for their conservation as well as the study of the plant community structure, species composition and the vegetation pattern of the oasis. A total of 86 stands were selected and located on the False Colour Composite (FCC) to represent major apparent variations in physiognomy and vegetation and in the edaphic features of the major types of habitats present in the study area (Figure 4). In selecting each stand, a reasonable degree of visual physiographic and physiognomic homogeneity and a minimum degree of disturbance were ensured. In each stand, plant species where identified and presence/absence data were recorded. Samples from the recorded species were collected and prepared as herbarium sheets for identification. Floristic identifications were made according to Täckholm (1974), and the Latin names of the species were updated from Boulos (1995).

In order to assess each habitat, the following mathematical procedure was applied: data on the degree of threat and the ecological and economic value for each species were assembled and used for calculating a conservation value (CV) (Salem, 2003). Information on the economic value of the recorded species was taken from Boulos (1983); Boulos (1989); Le Houérou (1985); Ayyad (1986), and Heneidy & Bidak (2004). The CV for each species, as a function of four criteria (each scored out of 10), were added to yield a value out of 40, which was then divided by four to produce an average conservation value (ACV), out of 10, for each plant species recorded in Moghra Oasis. The ACVs for all species occurring inside the major habitats in Moghra Oasis were summed up to produce a cumulative average conservation value (CACV) for each habitat. These values were used as an indicator to highlight the areas of importance for conservation. There were 22 species recorded in Moghra Oasis (of which only 12 were recorded by Girgis *et al*. (1971) and Zaharan & Willis (1992)). These species belong to seventeen families, half of which belong to gramineae, chenopodiaceae and compositae families. Through field studies, nine major habitats where distinguished: reed swamp vegetation, salt marshes, salt marshes covered by sand accumulations, sand hummocks/salt marsh transition, sand hummocks, sand dunes slopes, sand dunes, sand plains and gravel desert. These habitats support the growth of about 31 species, all of which are perennial species. Most of these species are important grazing plants.

These species are related to three different life-forms, the majority of which are chamaephytes (53%), while the remaining 47% are either geophytes or phanerophytes. The life-form composition reflects the response of the vegetation to variations in certain environmental factors. The life-form spectrum is thought to be a hereditary adjustment to the environment (Schwartz, 1939). The dominance of chamaephytes and geophytes in the study area would seem to be a response to the hot dry climate and to the prevailing environmental conditions (high salinity).

Many products used by humans such as medicines and industrial products are in fact derived from plants. The economic value of plants species is also considered according to medicinal values, grazing values, fuel wood production, and other miscellaneous uses. Most of the species recorded in the present study are multipurpose species (86.4%) of which 91% have grazing value (about 45% of them are highly palatable and are under threat from overgrazing in the studied habitats). About 81.8% of the recorded species are important for use in traditional medicines, 54.5% are used as fuel wood and 36.4% have many miscellaneous uses including as food products, leather tanning, and the construction of desert shelters, fences and so on. About half of the species recorded are considered in the vulnerable to endangered range in terms of their conservation status; this highlights the need for extensive efforts to limit threats to these species, especially from grazing pressure. Further reading on the vegetation types found in OBR can be found in the SUMAMAD publications referenced in this volume as UNESCO, 2005 and UNESCO, 2007.

3. Socio-economic characteristics of the study area

In the study area the local population is divided into tribes or *Qabael*, which is subdivided into sub-tribes, *Ailat*, where members do not own land but live within its boundaries. In Bedouin societies the differentiation between family and household is unclear. The Arabic word, *Aila*, is used to refer to a sub-tribe – literally meaning family. *Qbait* used to refer to an extended family, which may or may not live in a single household – literally meaning house. On average, the household size is composed of between 14 to 17 persons made up of children and adults, women and men. Most men have several marriages and their extended family members include grandparents and unmarried young men.

In the northwestern coastal desert in general, and particularly in Omayed Biosphere Reserve and its hinterland, the local community is nomadic and semi-nomadic with a tendency towards sedentarization due to government policy. This process began about thirty years ago when the Bedouins began to build stone houses. However, this does not affect the mobility of house dwellers for grazing or that the entire family live in tents.

The population in Northern Omayed is the most sedentary, which is probably encouraged by registered land holdings. The degree of sedentarization decreases towards the south where up to half of the Bedouins are still semi-nomadic. The community is characterized by inherited Bedouin traditions and values, which is both material i.e. seen in handicrafts, housing patterns, tools, clothing and so on, and immaterial i.e. through language, poetry, song, dance, and cultural practices. In the study area, traditional knowledge provides the basis of their existence and for local-level decision-making on many fundamental aspects of every day life. Due to the increase in the price of wheat, barley herders use onion remains (dry scaly leaves and hay) as a supplementary food source. According to local traditional knowledge, onion is seen as a good nutritive source of food and considered a fattening agent for herds.

The approximate number of people living within the proposed biosphere is as follows:

- Core Area(s): None permanently/None seasonally
- Buffer Zone(s): 600 permanently/100 seasonally
- Transition Area(s): 5500 permanently/2000 seasonally

The OBR comprises four villages; the numbers in terms of human population and families in each is shown in Table 1.

Village name/ number of families	Number of population/ (>30 years)
Omayed/195	1600 / 640
Sahel El Omayed/112	1280 / 490
Shammamah/68	660 / 220
Awlad Gebreil/60	465 / 120
Total (average)	**4000 (1470)**

Table 1. Population distribution of the four villages in OBR.

Major economic activities: Raising herds by grazing, intensive quarrying, and rainfed cultivation of grain crops, vegetables and orchards depending on water availability (mainly rain). Irrigated land agriculture is another potential activity which was introduced thanks to the extension of an irrigation canal from the Nile delta to the region. The economic revenues of the local community are mainly from trade in animal husbandry. Sheep breeding is the most common form of animal husbandry in the area. During the summer most of the flocks are kept close to the permanent dwelling place of their owners, sometimes sending their animals to the escarpment or further south for grazing as well as to Moghra, which is considered by the local community as a very important grazing alternative during the dry season.

Innovative activities that have recently been developed in the region include:

1. running groceries and trading in agricultural products;
2. the sale of electrical goods especially after the introduction of electricity in the region;

3. transportation by trucks commonly called *kareta*;
4. private sector employment;
5. brokering of land and houses.

Major environmental/economic constraints: Land degradation, habitat fragmentation, overgrazing, loss of biodiversity, salinization of soil, and the over-exploitation of mineral and water (groundwater) resources. The economic constraints stem from the general economic status of the local inhabitants (that range from low to moderate), and are due to the following:

- absence of a permanent source of income (revenue);
- lack of skills;
- major activities are seasonal (agriculture and grazing);
- spread of unemployment and thus poverty.

Women in the Bedouin community have an important role in managing and maintaining the family economy; the women ward off poverty by raising and selling animals, and being skilled at wool handicrafts. However Bedouin traditions are obstacles that inhibit women from going out to sell their handicrafts. Women are responsible for the daily running of the household including food preparation, carpet weaving, and poultry breeding as well as the occasional cultivation of small vegetable plots. They are indirectly responsible for significant contributions to in-kind family income. Their cash contribution is however minimal.

Bedouin law or *urf* (traditional custom law in Arabic) plays an important role in the community and is highly regarded by local people. In case of conflict, the community prefer to take the case to an aqila rather than the police. This social way of settling problems is more effective and efficient than going to the police. *Urf* is implemented through meetings where a set of roles for resolving disputes and dealing with acts and agreements are approved.

Bedouin communities are under stress either due to the harsh natural environmental conditions, to which local communities have mostly adapted, or due to the inefficient provision of social services. In terms of environmental stresses, Bedouin communities suffer more during the hot dry seasons because of the implications of water scarcity. They have their ways and means to combat these stresses such as moving their herds to Moghra Oasis, storing water in cisterns, transporting water using water tanks and trucks and so on. They have also built their houses in a naturally insulated way using palm midribs, and with windows directed towards the north. In summer they prefer to install tents outside their houses in the direction of the wind as it is more aerated and convenient. In addition, Bedouin communities living in the coastal region generally suffer less because of the better environmental conditions attributed to higher rainfall. This means greater productivity from orchards (particularly figs) and rangelands which enables a relatively better quality of life. Even in dry seasons, communities living in the coastal region can cope with difficulties associated with environmental conditions because of their accessibility to facilities e.g. transportation, potable water through water pipelines, electricity etc.

Comparatively speaking, the living conditions of the local communities living inland are very harsh where water scarcity and a lack of facilities and social services abound. However, although social services are provided to local communities in general, they lack staff, equipment and capacity and are not adapted to meeting neither the needs of the local communities nor the requirements expected from living in a desert environment.

4. Conservation of natural resources, community development and scientific information

4.1. Biodiversity

4.1.1 Richness of plant species

A total of 251 species were recorded in Omayed Biosphere Reserve of which 131 are perennials and 120 are annuals i.e. therophytes. These species belong to 169 genera and 44 families. The composites have the highest contribution of the total flora (15.9%), followed by grasses (13.2%) and legumes (12.8%). Thirty-two species (twenty-two perennials and ten annuals) have wide ecological amplitudes (recorded in at least six out of the seven prevailing habitats). These species are:

Perennials: *Allium roseum, Echinops spinosissimus, Plantago albicans, Anabasis articulata, Echiochilon fruticosum, Salsola tetrandra, Artemisia herba-alba, Gymnocarpos decander, Salvia lanigra, Asphodelus ramosus, Helianthemum lippii, Scorzonera undulata, Atractylis carduus, Lotus creticus, Suaeda pruinosa, Carduncellus eriocephalus, Noaea mucronata, Thymelaea hirsuta, Cynodon dactylon, Lygeum spartum, Zygophyllum album* and *Deverra tortuosa*.

Annuals: *Adonis dentata, Hippocrepis areolata, Rumex pictus, Astragalus annularis, Ifloga spicata, Schismus barbatus, Filago desertorum, Malva parviflora, Senecio glaucus subsp. Coronopifolius* and *Matthiola longipetala subsp. Livida.*

Highest species richness is found on the inland ridges (160 species) and non-saline depressions (156 species), and those of lowest species richness are found in the rainfed farms (65 species) and salt marshes (23 species). Conversely, the habitat of the highest number of unique species is the coastal dunes (35 species) (Table 2.). Eighteen species are restricted to the western Mediterranean region, in the area of the Omayed Biosphere Reserve: *Asparagus aphyllus, Fagonia cretica, Lotus polyphyllos, Centaurea alexandrina, Helianthemum sphaerocalyx, Prasium majus, Centaurea pumilio, Hyoseris radiata subsp. graeca, Rhodalsine geniculata, Ebenus armetagie, Leontodon tuberosus* and *Thymus capitatus* are perennials; and *Brachypodium distachyum, Daucus syrticus, Hyoseris scabra, Crucianella aegyptiaca, Hippocrepis cyclocarpa, and Matthiola longipetala subsp. hirta* are annuals.

Habitat	Perennial		Annual		Total	
	All	Unique	All	Unique	All	Unique
Coastal dunes	74	19	53	16	127	35
Salt marshes	17	2	6	1	23	3
Saline depressions	52	3	43	1	95	4
Non-saline depressions	78	4	78	10	156	14
Inland ridges	79	7	81	9	160	16
Inland plateau	59	4	46	2	105	6
Rainfed farms	35	1	30	3	65	4
Total	**131**	**41**	**120**	**42**	**251**	**82**

Table 2. Species richness of the major habitats in Omayed Biosphere Reserve. The unique species (one of the criteria that is used in assessing the nature reserves) to each habitat are indicated.

4.1.2. Endemic, rare and threatened species

There is only one rare endemic species called *Helianthemum sphaerocalyx* (Cistaceae) that inhabits the coastal dunes in this region. According to the scheme of rarity forms (Rabinowitz, 1981), forty rare species were reported in Omayed Biosphere Reserve of which 23 perennials and 17 annuals. Moreover, the species of unique occurrence in the habitat of coastal sand dunes are considered threatened because of the severe devastation of their habitat as a result of the construction of summer resorts. This process has lead to habitat fragmentation (Salem, 2003).

4.1.3 Noteworthy species

Noteworthy species that have invaded the area differ from each other not only in time and mode of introduction but also in terms of the degree of their establishment in various local artificial, semi-natural or natural coenoses (see Simpson, 1932; Drar, 1952; Walter, 1971, El-Hadidi & Kosinova, 1971; Täckholm & Boulos, 1974, Hejny & Kosinova, 1977). Four species (*Cynodon dactylon, Aster squamatus, Artemisia monosperma and Potamogeton pectinatus*) have started to invade the Omayed Biosphere Reserve as a result of recent human impact.

4.2. Soils

All soils in the area are considered to be very young and immature and highly influenced by the geological and geomorphological conditions of their formation. The scarcity of water within the soil in terms of the leaching of soluble components from the soil itself restricts the extent of soil formation processes.

Soils are classified into three categories: excessively calcareous soils containing more that 60% carbonate; very calcareous soils containing from 20% to 60% carbonates, and calcareous soils with less than 20% carbonates but containing at least some calcareous elements (> 2 to 3%). Soil texture varies from sandy to sandy loam, with evidence for the sandy and loamy sand textures being associated with aeolian contributions. Generally, the chemical analyses of these soils indicate that they are characterized by low salt content. Organic matter and total nitrogen content are relatively higher in the cultivated (olives and figs) soils than in un-worked areas; calcium carbonate is generally very high in the coastal areas. Soils in the transitional areas on north-facing slopes contain more organic matter, phosphorus, total soluble salts, calcium and potassium than those on south-facing slopes. Soils of salt marsh and saline depressions contain more soluble salts than elsewhere.

4.3. Water Resources

The existing water resources are as follows:

4.3.1 Groundwater

The important groundwater aquifers in the Omayed Biosphere Reserve are classified into the following categories: dune sand accumulations (Holocene); oolitic limestone (Pleistocene); and fissured limestone (Middle Miocene). The hydrogeologic unit of dune sand accumulations (Holocene) consists of unconsolidated calcareous sand of high porosity. Such accumulations act as good local reservoirs for the directly precipitated rainfall on the coast, and are tapped by a number of wells to yield water of low salinity (ultra-fresh water). The oolitic limestone forms the most important aquifer throughout the region to the west of Alexandria. It covers the whole coastal plain forming elongate ridges. The oolitic limestone extends southward from the coast line to about 10 km on average. The foreshore oolitic limestone ridge is characterized by less cementing materials compared with inland ridges and hence it has greater porosity. The source of groundwater found in the oolitic limestone ridges comes either from direct infiltration and percolation of annual rainfall on the ridges or from rainwater falling on the tableland located to the south. The fissured limestone (Middle Miocene) forms the underlying rocks of the entire area and is composed of limestone with few clay intercalations. Such limestone may be dolomitic, marly, clayey or chalky according to the local environment of sedimentation. A small scale homoclinal and synclinal folding and fissuring appear to be the more common structural features along the coastal zone. Such structural conditions have their effect on the groundwater occurrences in this area. Consequently, groundwater occurs in the form of separated sheets accumulated above the contact with the impervious clays alternating with the porous limestone. Miocene formations have no importance as an aquifer eastward from El Alamein.

4.3.2. Runoff water

Runoff is the main source to the south of Khashm El-Eish and directly at its northern sloping surface.

4.3.2.1 Hydrophysiography and drainage pattern

The northwestern Mediterranean coastal zone can be differentiated into two main physiographic provinces: the elevated tableland in the south, and the coastal zone to the north. A great number of drainage lines dissecting the elevated tableland acts as a major watershed area. Rainwater flows to the north following the regional slope of the tableland surface either towards the low coastal plain and/or towards the sea. The remaining rainwater infiltrates through joints that feed the lower limestone aquifers. However, the presence of a thin hard crust accelerates surface runoff to the north as occurs in the case of Khashm El-Eish. The low coastal plain acts as a collecting basin for the rainfall and runoff water from the southern tableland. The coastal ridges lead to the conservation of soil and surface water, meanwhile the elongate depressions act as collecting basins for the runoff water from both the ridges and the tableland. The surface hydrological conditions are generally controlled by many meteorological and physiographic factors such as evaporation, evapotranspiration, surface runoff and infiltration.

4.3.2.2 Evaporation and evapotranspiration

The evaporation intensity is generally affected by air temperature, air humidity, wind speed and solar radiation. The measured values of evaporation in the meteorological stations are actually pitche evaporation. The mean total annual evaporation increases southward where desert conditions prevail. Swidan (1969) noted that the values of free surface evaporation and potential evapotranspiration increased westward along the northwestern Mediterranean coast. On the other hand, these values increase southward as the temperature rises and the wind speed drops compared to the coastal areas.

4.3.2.3 Surface runoff

Surface runoff represents the excess of rainfall over evapotranspiration, when allowances are made for water storage on and under the ground surface. In the northwestern Mediterranean coastal zone, surface runoff is generally poor due to low average precipitation. However, some ephemeral streams may occasionally flow via channels of dry wadis already carved into the tableland during the Pleistocene.

4.3.3. Nile water (extended canal)

This new irrigation canal extends from Alexandria in the east to Alamin, 20 km west of Omayed, and passes through the two core areas of the biosphere reserve. This canal conveys water from the Nile to the desert mainly for supplementary drip irrigation, and supplies the non-saline depression containing dense cultivation. The main canal is connected to a network of branches made up of narrower canals that have caused habitat fragmentation in the saline depression. This has been observed through analysis of remote sensing images before and after canal construction.

5. Practices implemented for soil water conservation

5.1 Environmental Information System (EIS)

5.1.1 Satellite Image Analysis

SPOT-HRV imagery was the main source of data used in the present study. SPOT frames covering the study area has the path/raw number 107/188, were made available for September (common date in the data available for the study area) for 1987, 1993 and 1999. The image processing work used ERDAS/Imagine image processing software and was carried out at the Remote Sensing and GIS unit of the Department of the Environmental Sciences, Faculty of Science, University of Alexandria. A geodatabase was built by digitizing base maps and integrating field observations and attribute data using PC/ArcInfo software and ArcView GIS. The study area of OBR, covering about 722 km^2, was extracted as a subscene from each of the three SPOT frames, georeferenced and registered. False colour composite (FCC) images of the three subscenes were examined visually, and confirmation by visual interpretation was made through field investigations and ground truth using the base maps and aerial photos as a reference.

A GPS was also used to determine geographic locations and boundaries. The distribution of digital data of the three subscenes was examined through histograms and scatter plots, and the spectral signature of each land cover class was extracted. The three subscenes were processed by unsupervised classification into five major land cover classes, and the results were compared to assess land cover changes through time. Classification accuracy measures were estimated for the resulting classification using confusion matrices. Field surveys were conducted in order to verify the accuracy of the results of the satellite image classification and to compare it with different dates, as well as to check the existence of the documented vegetation list for each habitat (presence/absence). In a situation where a dominant or a co-dominant species in a particular plant community is absent compared to previous records, this would be considered an indicator of habitat deterioration. Samples from all the habitats in the OBR were surveyed and vegetation composition checked against documented lists. Soil conditions were also recorded for each habitat.

5.1.2 Participatory Geographic Information System (PGIS)

The spatial database produced is based on an automation of base maps and satellite image interpretation. The spatial database of OBR was extracted and added to the existing digital geodatabase. The whole process of establishing the geodatabase involved the following:

1. Interpretation and classification of the existing satellite image.
2. Spatial and aspatial data automation to build on the existing geodatabase.
3. Automating the GPS locations of the soil and water samples according to database forms and adding the physical and chemical analysis of these field samples.
4. Automating the maps produced by the local community members in the PGIS process to produce land resource maps based on traditional knowledge.

The current geodatabase layers as shown in Table 3 was used for the production of a standard base map used by all the project members for field investigation, sampling and PGIS.

Meetings were arranged to bring together the project team and identify local focal points (men and women), which took the form of relaxed semi-structured interviews and open meetings that followed a guiding

Title	Type	Attributes	Reference	Comments
Sea area	Polygon	ID, Area	1	Layer to describe the water wells recorded by the observatory team.
Protectrate wells	Points	ID,	2	Layer to describe the water wells recorded by the observatory team.
Standard topo map	Points	ID,	1	Layer to describe the water wells recorded on the military topographic maps.
Settlements	Points	ID, Title	1	Layer to describe the settlements recorded on the military topographic maps.
Roads	Line	ID, Title, Label	1	Layer to describe the transportation network that recorded on the military topographic maps.
Oil pipes	Line	ID, Title, Length	1	Layer to describe oil transition pipes recorded on the military topographic maps.
Epoints	Points	Elevation	1	Layer to describe elevation points recorded on the military topographic maps.
Contours	Line	ID, Contour	1	Extracted using interpolation method to Elevation points.
Canals	Line	ID, Label, Kind, Title, Length	1	Layer to describe drainage/canals network recorded on the military topographic maps.
Depression	Polygon		1	Layer to describe the natural borders of El-Qattara depression that recorded on the military topographic maps.
TIN	TIN			Extracted from the Elevation points recorded by military survey.
DEM	Grid			Extracted from the Elevation points recorded by military survey.
Slope	Grid			Extracted from the Elevation points recorded by military survey.
ASPECT	Grid			Extracted from the Elevation points recorded by military survey
HILLSHAD	Grid			Extracted from the Elevation points recorded by military survey.
Participatory GIS maps	Polygon	ID, Landuse	3	Land resouce maps that presented by local community individuals.
Field Observations	Points	ID, Name, N, E, Z, Depth, pH, Temperature, Salinity, EC, soil moisture, soil structure.	4	Water wells that recorded in fields, soil samples location.

Table 3. The Master Database Content

anthropological framework outlining the sequence of events and points to remember. The main investigating tools used for the PGIS were hard copies of base maps that were produced and printed from the geodatabase of the project superimposed on satellite images of the region.

The local inhabitants in the study area were provided with sheets of the base maps and coloured pens and asked to draw boundaries of the best rangeland areas, freshwater resource areas, and best cultivable lands. They were also provided with a satellite image of their area and asked to mark the boundaries of its different zones based on their recognition of the habitats. The information obtained included local soil types and their classification and distribution within the landscape, local habitats, water catchments areas, and local rangeland systems and indigenous agro-ecological zones.

This information was then transformed into geographic data using a Global Positioning System (GPS). Individuals from the local community including women were asked to:

- Delineate major habitats and their spatial distribution and attributes.
- Identify optimal conditions for the occurrence of target plant species.
- Identify, delineate and monitor land cover changes.
- Plan orchard development and their spatial distribution.
- Understand the dynamics of pastoralism and the threats of its environmental impacts.
- Delineate areas of inappropriate land use and determine their environmental impacts.
- Understand land tenure in relation to natural resource management.
- Plan locations for rainwater harvesting reservoirs.

The whole process will involve the following:

1. Satellite image interpretation and classification.
2. Spatial and aspatial data automation to build on the existing gegeodatabase.
3. Physical and chemical analysis of field samples, especially water and soil.
4. Identification of vegetation types and spatially locating their major habitats.
5. Recording the indigenous knowledge pertaining to the use of resources and conservation particularly the rangelands and water resources.

The establishment of the above master database based on the above methodology proved to be invaluable for use in the evaluation of the study site; it facilitated comparative evaluations with other study sites and dissemination of information amongst the partner institutions.

5.2 Land Evaluation Study

5.2.1 Soil profiles

Sixty-five soil profiles were taken in OBR for the land evaluation study and its suitability to different land uses. According to chemical and physical properties of the soil, the following categories – from El-Hammam to El-Alamein – were identified.

5.2.2 Infiltration rate

Infiltration rate was measured during the summer season in five sites (5, 11, 20, 32, and 55) with sandy and sandy loam soil texture using a double ring infiltrometer consisting of two concentric rings (Figure 5); the rate of fall of water was measured in the inner ring while a pool of water was maintained at approximately the same level in the outer ring so as to reduce the amount of lateral flow from the inner ring and therefore measure the rate of infiltration (which is the difference between the two levels).

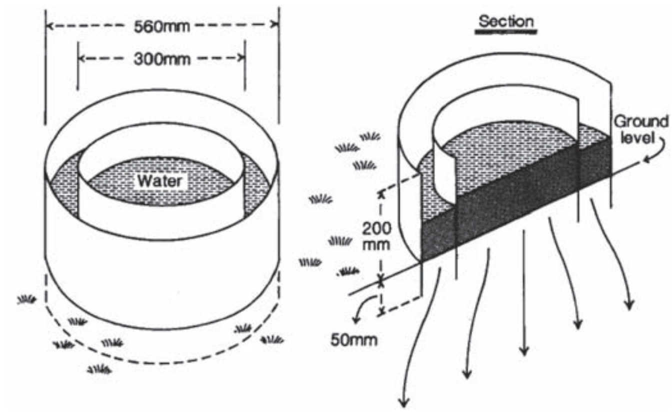

Figure 5. Double Ring Infiltrometer.

5.2.3 Land evaluation

The different land characteristics influencing soil suitability for irrigation are rated and a capability index for irrigation (CI) is calculated by multiplying all rating factors as follow (Sys et.al.1991)

$$CI = A * \frac{B}{100} * \frac{C}{100} * \frac{D}{100} * \frac{E}{100} * \frac{F}{100} * \frac{G}{100}$$

Where:
CI = Capability index for irrigation
A = rating of soil texture
B = rating of soil depth
C = rating of $CaCO_3$ status
D = rating of gypsum status
E = salinity/alkalinity rating
F = drainage rating
G = slope rating

The capability classes (soil grades) are defined according to the value of (CI) as presented in the following table:

Capability Index (CI)	Class	Definition
> 80	I	Excellent
60-80	II	Suitable
45-60	III	Slightly suitable
30-45	IV	Almost unsuitable
< 30	V	Unsuitable

Table 4. Classes of capability index (CI).

5.3 Propagation of selected plant species for rehabilitation purposes

The aim of this activity was to evaluate the propagation capabilities of wild species in terms of grazing value as well as ecological value in the conservation of degraded ecosystems in OBR. The identification of species and the selection process was based on the following criteria:

- Ecological value of species and its grazing potential.
- Native species.
- Testing the degree of germination under lab conditions.
- Evaluation of various means of breaking dormancy.
- Value of species on the basis of social and economic considerations.

5.3.1 The experiment

The seeds of ten perennial species representing different life forms were collected for the present study. The experiment started by treating seeds to break their dormancy. Some seeds were treated by sowing to promote germination and/or break dormancy by incubation at 30–35ºC, cold incubation, dipping in dilute H_2SO_4, or scarification prior to planting. Emergence of a radicle was considered a criterion of successful germination.

As species differ in their speed of germination, seeds were set to germinate in Petri dishes in the laboratory during July–August (2005) at varying times. Prior to planting, and in order to break the dormancy, some were treated by scratching, immersing in diluted HCL, refrigerating and so on. Germination was carried out with moist filter paper and 12-hour days at 27ºC. Seeds used in the soil germination experiments were not pre-treated. All seeds were sown at the same depth (1 cm) so that no seedling received more favorable soil moisture due to depth than another. The soil conditioner used for testing the water holding capacity (see section 5.5.6 of this report) was used to detect its effect on seed germination. It was mixed with the soil by a ratio of 1:3 weight/weight in plastic pots in open-air environment. Emergence and survival of seedlings were monitored daily up to 18 days after planting, when mortality ceased. All pots were kept moist on the first two days of planting. Preliminary experiments were carried out to determine the water field capacity of the soil. Each treatment was represented by two replicates of seeds.

5.4. Standing crop phytomass and production

Annual variation in the production and turnover rate, and the accessible (consumable) dry matter production of the sub shrubs and forbs together (maximum values of the different seasons) were estimated for different habitats. The standing crop phytomass of a species at any time of the year may be distinguished as grazeable (new-growth) and ungrazeable phytomass. The ungrazeable phytomass includes the underground organs (roots and perennating organs) and the aboveground woody organs (stem and branches). The grazeable phytomass is represented by the seasonal additions of new-growths (taking into consideration that a minor part is consumed by heterotrophs other than the domestic grazing animals).

5.5 Palatability and Nutritive Value

In the coastal Mediterranean region numerous factors were considered when classifying a plant as palatable or not: phenological stage, morphological form, odour, taste, chemical composition and its abundance relative to associated species (UNESCO, 2005). The topography of the habitat, climate and state of the animal itself are all contributing factors (Heneidy & Bidak, 2004). Many physical and chemical factors influence the palatability of plant species, of which animal behavior and chemical composition are the most important. The chemical constituents in plants and their digestibility vary independently of different organs, and depend on plant age (Le Houéou, 1980; Heneidy, 1992). Of these, crude protein (CP) is viewed classically as an indicator of the nutritional value of food for ruminants.

Abdel-Razik *et al*. (1988a, 1988b) reported that the analysis of samples, which represent the diet chosen by the herbivores, indicated that the grazeable proportion of the phytomass of most species had, in general, a higher nutrient concentration than the non-grazeable proportion; this may reach several fold in shrubs. The nutrient concentration in the grazeable phytomass of the vegetation growing in the ridge habitat was higher than their concentration in similar plant parts in other habitats.

5.5. Water conservation

5.5.1 Water Quality Assessment

In order to obtain data on water quality several field visits were conducted by the project team where different types of water samples were collected for lab analysis to assess water quality. These samples were collected from cisterns, irrigation canal, and from trenches (groundwater), as well as water from Moghra Oasis (OBR hinterland). Water samples were collected from a number of cisterns following a rainfall event. Some of the cisterns in the southern part of OBR did not collect rainwater due to their poor condition or due to the decrease in rainfall in the south. Four water samples were also collected from El-Hammam canal, stored tap water, Alexandria-Matrouh water pipeline, and the wastewater plant in Sahel Omayed village. Nine groundwater samples were collected from the northern part of the OBR in Omayed and Sahel Omayed villages. Four groundwater samples were also collected from Moghra Oasis. All these samples were chemically analyzed for major cations (calcium, magnesium, sodium and potassium) and anions (bicarbonate, sulfate and chloride) and some minor constituents (nitrate and boron), in addition to field measurements such as temperature, pH and electrical conductivity.

5.5.2 Water Conservation

Various ways and means of achieving the goals of water conservation in OBR and its hinterland were studied, and are briefly described below:

1. Rainwater harvesting.
2. Rehabilitation of old Roman cisterns for re-use by the local community.
3. Low cost water desalination.
4. Saving irrigation water by cultivation of drought tolerant crops.
5. Using soil conditioner for water conservation.

Rainwater harvesting: can be implemented on the roofs of the Bedouin houses, but how much rainfall can be collected from roofs of houses? Not all the rain that falls can actually be collected. A small amount of rain 1/10 of an inch (0.25 cm) will be needed to wet the roof and fill the roof washers. Efficiency is usually presumed to be 75–90% depending on system design and capacity. Once storage tanks are full any additional rain will not be collected (overflow). Water harvesting design could accommodate this problem and use the excess water for groundwater recharge. A filtration system must be used to filter debris from rainwater as it flows from the collecting roof before it enters the storage tank, which may be made of ferro-cement. A catchment area of a roof usually measuring 20 m2 or more is sufficient.

Roman cisterns rehabilitation: Field survey shows that many cisterns in the OBR are present and distributed throughout the entire area. A number of them were recently repaired and managed to collect rainwater in December 2004 and January 2005, but as these cisterns are a water source for livestock, the nearby surroundings have become overgrazed. Our criteria for repairing more cisterns are based on the following:

1. The location of the cistern relative to ground slopes as will be shown on the digital elevation model and in areas where converging surface flow occurs.
2. Cistern condition where those in poor condition are excluded.
3. Distribution in the entire area of OBR.
4. Its location relative to rainfall spatial variation (not in the extreme southern part of the OBR).
5. The cost of rehabilitation: in some cases the cisterns are in good condition but they do require maintenance, and a ferro-cement precipitation basin should be made to allow the suspended load in runoff water to settle before entering the cistern.

Solar water desalination: Some winter seasons in OBR can experience no rain so another source of drinking water is needed to compensate for dry seasons and years. A water desalinization system based on solar energy was suggested to conserve water. The system has a lifespan of about twenty years. The untreated water is most commonly extracted from an intermediate tank or taken directly from a pipe or well. The system is illustrated in Figure 6 and works as follows:

- With the help of a radiation sensor a patented electronic monitoring system regulates the quantity of untreated water for the collector or a whole group of collectors. The intake of untreated water is performed in such doses that around 50% evaporates and 50% remains as brine. This brine could be used to support fish farms or to extract pure salts as an additional source of income.

- Only the exact amount of untreated water passes into a channel for untreated water in the collector '1', and drips over wicks onto a black absorber fleece '5'. This special fleece can handle UV rays for many years and is food proof. The heat insulation '6' prevents losses of energy by the collector bottom.
- Using only the energy from the sun, the moist fleece heats up to temperatures of 80–90°C. Around 50% of the untreated water evaporates and condenses under the cooler glass cover '4'. This condensation is the actual drinking water and it flows into a condensation channel '2', and out of the side of the collector.
- The remaining untreated water '3' leaves the collector and carries dirt and salt from the fleece. However, the remaining untreated water is also purified on its way through the collector by a combination of UV rays (fertilization) and high operating temperature.

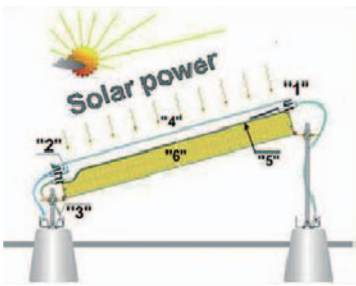

Figure 6. Solar water distillation system

The well drilled for use by the solar desalination system was 10 cm in diameter. It was built three years ago by the owner in the hope of finding freshwater but instead contains only brackish water with the same salinity as the Mediterranean Sea. As the water could not be used for irrigation the well was closed and the surrounding land was not cultivated as planned. The owner donated an area of 150 m^2 to the project including the well. As the cells produce 6–8 litres of distillate per m^3/day, four cells with a total surface of 10 m^2 could deliver 60–80 litres/day. A flat pond evaporates about 6–10 litres of water per m^3/day, 10 m^3 should be enough for the rest of the brine to evaporate.

Saving irrigation water by cultivation of drought tolerant crops: The Agriculture Research Center, Ministry of Agriculture, has concentrated its efforts to produce a new wheat genotype that is tolerant to water stresses and adapted to salinity. After several studies and experiments, a new drought resistant cultivar of wheat was produced by Nubaria Agriculture Research Station. It is a breed of two wheat cultivars, Sakha 8 (an Egyptian cultivar), and Nesser produced by ICARDA. This cultivar was cultivated in a soil of similar physical and chemical characteristic as the study area. It requires only two irrigations; the first at the time of sowing and the second at thirty days after planting, it is then left to rainfall conditions. The fertilizer regime is also indicated in terms of type and time of application (all data is provided in Abd-Allah, 2002). Seeds of the above cultivar were distributed to two selected Bedouin farmers in OBR who cultivate wheat on their lands. They were asked to cultivate this new cultivar in addition to the cultivar they normally cultivate.

Using soil conditioner for water conservation: An experiment to test the water holding capacity (WHC) of soil samples from OBR with and without the application of the soil conditioner was conducted in the lab. The details of the experiment are as follows:
Sandy soil samples were collected from different sites in the northwestern coastal zone. In the first aliquot two saturated paste extract of the collected samples were prepared. A recorded weight of water (depending on the soil type) and weight of soil (500 g) was used to prepare the extract. The moisture content of the soil was determined with a second aliquot. The WHC of the soil is determined from the amount of water in the soil as received (collected) plus the amount added to produce the saturated paste:

WHC (mg /g) = (Ws*%M + Ww)/(Ws-Ws*%M)
Ws = mass of soil as received used in the saturated paste preparation
%M = % Moisture
Ww = weight of water used to prepare the saturated paste

Therefore WHC represents the approximate amount of water a soil can retain following irrigation (i.e. about 24–48 hours). The time allows excess water to drain from the macro pores, and the soil is at field capacity (FC). About 30–50% of the available water is depleted at the time of irrigation. The unavailable water can't be used by crop plants because it has been adsorbed too tightly for plant roots to extract. By noting the depth to a restrictive layer, the depth of the root zone was established using a glass container. The work was repeated in the presence of soil conditioner mixed with sandy soil.

6. Income-generating activities

The current analysis represents an attempt to study the *status quo* of the population of the western coastal desert particularly at the hinterland of OBR. It focuses on the nature of the available economic activities and the technical professional skills through which the infrastructure for a productive simple society can reach its potential and thus comply with the surrounding natural and human resources. The criteria for selecting the appropriate income generating project should comply with the following:

- Focusing on poor and disadvantaged groups.
- Sharing and integrating the technical aspects of the project with members of society.
- Its activities should appeal to the target group.
- Improving living conditions and providing a fixed income for the families, and which does not cause damage.
- Project management should consider the availability of human resources, and the job description of members should be made available.
- To attain project success and sustainability, the level of cooperation between parties should be clarified.
- Communicating with society and linking by cooperating with participating members.

6.1 The Projects

6.1.2 Sewing crafts and embroidery

6.1.2.1 Project description and justification

This project is implemented for women of the Bedouin community (Figure 7). It was observed that girls in the Bedouin community are allowed to go to primary school only up to a certain stage, once they reach 12–14 years they are not allowed to leave the house to attend school or even go to the market. This project therefore targets women to help them use this time to develop skills and earn money by implementing a project that can be run from home and within the female community made up of family members or neighbours. The project takes place in one of the houses where a room is devoted to sewing and hands-on training of the younger women by the older family members such as an older sister or mother. Hence, the teacher and the student are from the same family. The training is carried out three times a week. Families expressing willingness to join the project should nominate a project manager – an older family member – who signs the contract and receives a sewing machine and the material (cloth, threads and all related items). The project was very well received by the women in the community and the SUMAMAD team was overwhelmed by the number of women wishing to participate and who sought continuity and expansion of the project.

6.1.2.2 Project objective

The project objectives include:

- Training as many girls on sewing and embroidery.

- Providing incentives for developing skills (a sewing machine).
- Achieving income-generation through selling the products within the community.

6.1.2.3 Follow up

The project was followed up two weeks from the project onset where the seriousness of the process was assessed by:

- Measuring the speed of learning.
- The amount of dresses and costumes produced.

6.1.2.4 Project economy

The cost of the sewing machine and the associated material (without electricity costs) is about L.E.1000 (~USD180), enough to produce ten items a month. Each piece is sold for about L.E. 30–35 (~USD5–6) depending on the fabric, size, and market opportunities. The total revenue is about L.E. 330 (~USD60) per month. Figure 7 shows the project stages, and some of the clothes produced.

6.1.3 Establishing an in-house factory producing dry figs

This is made up of five sections: an assortment unit, an innovative solar drying unit, a quality control unit, a packaging unit and a distribution unit. Fig plantations are the most abundant in the project site producing high quality figs in only three months of the year. During this period production is high so the figs are sold cheaply. Due to its abundance fig fruit waste occurs in transport, packaging, and the low market opportunities. Following discussions with the local community the project was started and there was a great willingness to participate. In the next phase, a solar unit will be examined for its suitability in drying figs, which is newly developed in Egypt for drying vegetables and fruits. The unit cost, capacity, and production will be assessed in the next phase, as will its effectiveness and reliability.

Figure 7. Clothes produced by Bedouin women.

The process of drying figs is an in-house process that can be implemented in the yards of the Bedouin houses. This means that youths aged 18–25 can participate in this process and earn their own money by using the by-product and otherwise wasted figs from their family farms. At least two family members are required for each of section of the process – so at least ten family members among the youth per household could be involved in the process.

6.1.4 Registration of identity cards for women

In order for women to exercise their rights in society – to work and produce – the SUMAMAD project obtained identity cards for 150 women in OBR. These ID cards will enable women to register with health centres and mother and child programmes; be enrolled in adult education programmes; officially get married and claim inheritance, as well as register birth certificates for their children. The process was performed with the complete coordination and cooperation of the local authority in Hammam city, where the administration department devoted two social workers to fill in the official forms. This is considered a great achievement.

7. Results obtained

7.1. Environmental information systems

All data obtained from the field visits were geo-referenced and registered on the base map obtained from maps and satellite images. Digital Elevation Models were also obtained. All the resultant maps can be consulted in the publication referenced as UNESCO, 2005.

7.1.1 Satellite image analysis

The results of unsupervised classification were five classes for each of the 1987, 1993 and 1999 subscenes. The overall classification accuracy of the three classification procedures were 95%, 92% and 93% for the 1987, 1993 and 1999 subscenes, respectively. The process of change detection was based on post classification comparison of land cover classes, as pixel wise digital comparison proved to be inaccurate in this case due to differences in the SPOT-HRV sensor. The results of the process of land cover changes in OBR are demonstrated in Figure 8, which show the three FCC images and the three resulted classified images. The five land cover classes are

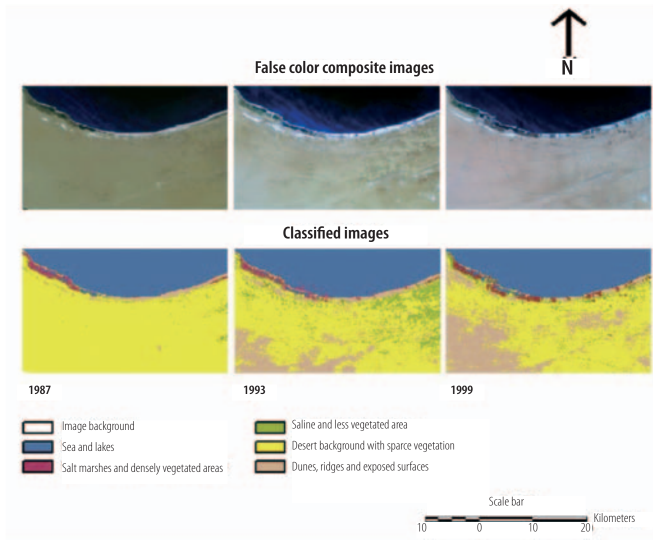

Figure 8. The three FCC images and the three resulted classified images.

Class no.	Color	Class identification		Absolute Cover (Km^2)			Comments
		Cover	Use	1987	1993	1999	
1	Blue	Sea & Lakes	Artificial Fisheries & Recreation	205.6	205.8	208.0	Beeches are suitable for recreation activities.
2	Red	Salt Marshes & densely vegetated areas	Scarce grazing and wood cutting	9.75	10.99	13.4	Summer resorts along the coast are included in this class because these resorts are densely planted artificially
3	Green	Saline depressions & less vegetated areas	Grazing, wood cutting, cultivation of crops and orchards	10.53	64.37	24.79	Salt tolerant species of figs, olives and almond that are appear in this class cultivated
4	Yellow	Non-saline depressions	Rain fed and irrigated cultivation, gazing, wood cutting, housing	477.9	322.19	288.04	The most productive habitat and the most suitable lands for rain fed cropping
5	Beige	Dunes exposed ridges, inland habitat.	Quarrying, Grazing, and housing	17.82	119.02	188.01	Quarrying activities have removed most of the ridges of the area.

Table 5. The resulted land cover classes of the three dates SPOT subscenes of OBR.

presented in Table 5, and a comparison in terms of land cover in km^2 was estimated.

The percentage cover of classes on the three dates is compared and illustrated in Figure 9. From the results shown in Table 5 and Figure 9, OBR is shown to have been subjected to huge environmental degradation due to land cover changes since 1987. Indicators of these changes are obvious in classes 2, 4 and 5. In class 4, the area of exposed surfaces has increased about nine-fold since 1987. This is mainly due to the intensive quarrying activities in the ridge habitats and in the inland plateau as well as the development activities taking place in the non-saline depression that comprises the digging of a network of irrigation canals to export water from the Nile, and natural processes mainly due to wind erosion. These activities are also coupled with the intensive establishment of summer resorts, shown in class 2, and which have almost replaced the coastal ridge habitat in OBR. The extent of these resorts is shown in red in images in the FCC and classified image.

In this context, an additional analysis (on-screen digitization) has been carried out to estimate the difference in area of the coastal dunes including slopes in the 1987 and 1999 subscenes. It was found that from the total area of about 25 km^2 of coastal dunes and its slopes in OBR about 19 km^2 remained in 1987 and only about 2 km^2 in 1999. This means that about 17 km^2 of the coastal ridges and its associated biodiversity and freshwater resources in the OBR has completely disappeared. It should be noted that this transformation began in 1987 but its rate has significantly increased in the last five years. These results are considered to be an important indicator of habitat loss and environmental degradation in the OBR.
The second indicator of environmental degradation is shown by the reduction in percentage of vegetation cover in the non-saline depression, which was mainly used for grazing and rainfed cropping. This decline is mainly due to the division of the non-saline depression habitat into land parcels for irrigated agricultural activities, where a network of irrigation canals was established. Despite receiving water throughout most of the year these canals have caused fragmentation and subsequent biodiversity loss. Together with the existing pressures exerted on this habitat from overgrazing and the uprooting of plants, the end result is a tremendous loss of the fertile soil surface which exposes the subsurface rocks to erosion and deterioration. From field surveys, it was found that out of the total area of 700 km^2 in the OBR, the area estimates shown in Figure 9 were revealed.

Colour	Class identification	
	Cover	Use
1. Blue	Sea & lakes	Artificial fisheries & recreation
2. Red	Salt marshes& densely vegetated areas	Scarce grazing and wood cutting
3. Green	Saline depressions & less vegetated areas	Grazing, wood cutting cultivation of crops and orchards
4. Yellow	Non-saline depressions	Rain fed and irrigated cultivation, grazing, wood cutting, housing
5. Beige	Dunes exposed, ridges, inland habitat	Quarrying, grazing and housing

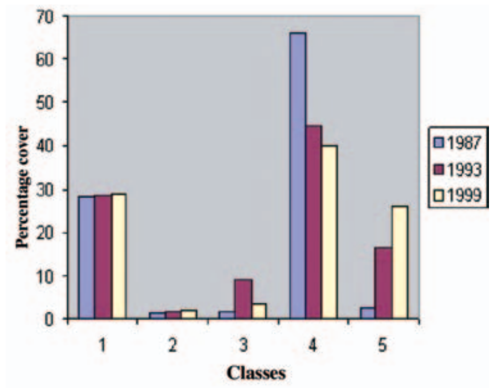

Figure 9. The percentage cover of classes in 1987, 1993, and 1999.

Table 6 next page, shows the area in km^2 (according to field work in 2003) of the major land use/cover classes in OBR.

7.1.2 Participatory GIS

Local community ability to geographically locate a zone with great accuracy on a base map as well as on a satellite image depends on their perception of dimensions when drawing free-hand on a white sheet. The size (surface area) they allocated to a certain location depended directly on the importance of this location to their livelihood. The PGIS approach led to a set of maps that faithfully represented the study, and was recognized

Land use/cover	Area (Km^2)
Bedouin settlements (4 villages)	3
Cultivated land	85
Infrastructure	12
Quarries	13
Agriculture investments projects and their buildings	33
Lands for national reclamation projects	252
Military areas	42
Summer resorts	25
Total	**465**

Table 6. Land use area distribution.

and adopted by the local community. The base map used for PGIS analysis and the resultant land resource map according to PGIS can be consulted in the publications referenced as UNESCO, 2005 and UNESCO, 2007.

7.2 Soils conservation practices and land evaluation

7.2.1 Field capacity

Field capacity (FC) is defined as the water content (%v) of the soil matrix approximating the water content of a saturated soil that has been allowed to freely drain. It is estimated as a hydraulic tension of 33 kPa (0.33 Bar) and dependant only on the soil texture and unaffected by salinity or gravel. In OBR, a good estimation of the field capacity of sandy soils is important in evaluating their suitability for irrigation. According to the standards of the U.S. Bureau of Reclamation, the available water capacity for irrigable soils is 3/48 in (7.5/120cm).

7.2.2 Infiltration rate

The infiltration rate of sandy soils in OBR reaches about 2.5–25 cm/hr. This measure is about 250 times more than clay soils (0.01–0.1 cm/hr) due to the large pore spaces and high saturated hydraulic conductivity. Under unsaturated flow conditions, water moves more slowly in sandy soils than in clays as a result of the lower moisture content and lower unsaturated hydraulic conductivity of the former (Bouma and Denning, 1972). The understanding of these relations is important for proper irrigation and drainage practices, especially in stratified soils. The measured infiltration rates for each site are presented in Table 7 below.

Site	Texture	Infiltration rate (mm hr^{-1})
5	Sandy	24.8
11	Sandy Loam	53.7
20	Sandy Loam	55.0
32	Sandy Loam	58.5
55	Sandy	26.7

Table 7. Mean steady infiltration rate (mm hr-1) of each site measured in summer.

7.2.3 Observed visual indicators of land degradation in OBR

The significant potential agents of soil degradation that could play a role in OBR were observed in the field and are summarized below:

1. *Water erosion*: In the OBR area, rainfall aggressivity is low to medium and vegetation cover usually low; soil erodibility is often high, especially in those soils having a sandy loam, sandy clay loam and silty loam texture representing the majority of soils in the area; sandy and loamy sand soils should be far less sensitive.
2. *Soil erosion by wind and sedimentation (soil burial):* Areas of diffuse wind sedimentation which when not distributed by cropping often takes the shape of hummocky lands; generally increasing biological productivity, soil thickness and fertility. This takes place in some areas of the saline depression in particular as well as the low hinterland areas.
3. *Soil fertility decline*: Due to erosion and the degradation of soil physical, biological and chemical properties. Soil fertility decline is not just a problem of nutrient deficiency but also of overgrazing, uprooting of native species, and salinization.

4. *Lowering of water table*: This usually occurs where extraction of groundwater exceeds the natural recharge capacity of the water table.
5. *Loss of vegetation cover*: Vegetation is important in many ways, it protects the soil from erosion by wind and water and it provides the organic material to maintain levels of nutrients that are essential for healthy plant growth. Plant roots help to maintain soil structure and facilitate water infiltration.
6. *Increased stoniness and rock cover of the land*: This is usually associated with extreme levels of soil erosion causing exhumation of stones and rocks.

7.2.4 Soil erosion mapping with universal soil loss equation and GIS

The goal was to establish spatial information of soil erosion using the Universal Soil Loss Equation (USLE) and GIS. A set of factors as identified in the USLE were studied and reviewed. These include the rainfall erosivity factor (R-factor), the soil erodibility factor (K-factor), the slope and slope length factor (LS-factor), the vegetative cover factor (C-factor), and the conservation practice factor (P-factor). Each factor consists of a set of logically related geographic features and attributes and is used as data input for analysis. The factor layers were collected from existing information and extracted from Landsat MT imagery. Analysis of daily rainfall data of the past two years gives the R-factor. Spatial K-factor was formulated from detailed reconnaissance soil map of the area.

A digital elevation model (DEM), interpolated from elevation contours was employed to generate the slope and LS-factor. Spatial vegetative cover, extracted from Landsat TM imagery, was used to determine the spatial C-factor and consequently the P-factor, values of which are based on experimental results.

Each of the above mentioned USLE factors was digitally encoded in a GIS database to eventually create five thematic layers. Overlay operation produces a resultant polygonal layer, of which each polygon is a homogeneous area with respect to each of the five factors. The USLE model calculation applied to the resultant polygonal layer gave values of soil loss in tons/ha/year. The study indicates that low erosion classes are located in areas of land used for agriculture where slope gradient is very low. High erosion classes concentrate on the Khashm El Eish ridge and its northern slope as well as areas where land is used for field crops with no conservation practice especially in the non saline depression (Figure 10). Areas marked with dark colours indicate the

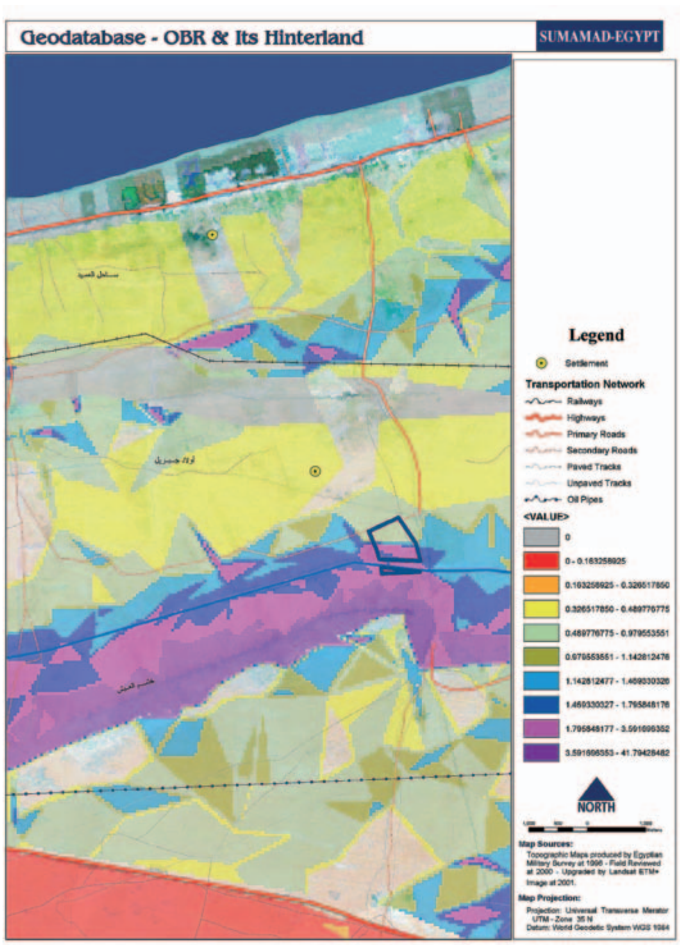

Figure 10. USLE model of soil erosion.

high erosion risk areas in OBR. To evaluate its reliability, the resultant soil erosion map was checked against existing soil erosion maps and data from field surveys. It was found to be satisfactory.

7.2.5 Land evaluation study

7.2.5.1 Soil profiles

Sixty-five soil profiles were carried out in OBR to assess the land evaluation study and the suitability to different land uses.

According to chemical and physical properties of the soil, the following categories – from El-Hammam to El-Alamein – were identified:

A) Non to slightly saline deep and moderate to shallow soils (EC < 4 dS/m).
A.1) Non-to slightly saline deep soils (0–90cm) with homogenous texture.
A.2) Non-to slightly saline moderate (0–50 cm) to shallow (0–30 cm) soils with homogenous texture.
A.3) Non-to slightly saline deep soils with heterogeneous texture.
A.4) Non-to slightly saline moderate to shallow soils with heterogeneous texture.
B) Non to slightly saline shallow soils with heterogeneous texture.
C) Moderately saline deep soils (EC 4–8 dS/m).
C.1) Moderately saline deep soils with homogenous texture.
D) Moderately saline shallow soils with homogenous texture.
E) Highly saline deep soils (EC > 8 dS/m).
E.1) Highly saline deep soils with homogenous texture.
E.2) Highly saline deep soils with heterogeneous texture.

The results of the land evaluation analysis indicated that 61 % of the soils in the study area are grade V (Figure 11) i.e. this soil type is unsuitable for agriculture under current

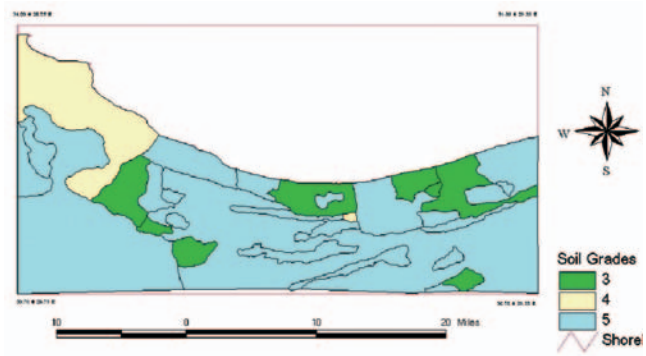

Figure 11. Distribution of soil grades in El-Hammam and El-Alamein area (Rashad, 2002).

conditions but it can be elevated to grade III and be slightly suitable for some agricultural practices. In addition, about 20 % of the soils are grade IV, meaning that this soil type is almost unsuitable for agriculture under current conditions. While 19 % of the soils are grade III, meaning that this soil type is slightly suitable and can be increased to grade II and be suitable for specific uses in crops for some agricultural practices. Moreover, 19 % of the total area is considerable and can cover a large area in term of its productivity if an agricultural strategy was carried out in the area (Rashad, 2002).

7.3 Propagation of selected plant species for rehabilitation purposes

Thirteen species were selected for the first trial of germination experiments, these were: *Lycium shawii, Hyocyamus albus, Citrullus colocyncis, Peganum harmala, Deverra tortuosa, Cenchrus ciliaris, Polygonum equisetiforme, Nitraria retusa, Lygos raetam, Datura innoxia, Reseda decursiva, Sesbania sesbane*, and *Panicum turgidum*. A preliminary experiment was carried out in the lab to assess the success of germination and the breaking of their dormancy using existing seeds (see Section 5.3.1). The experiment was not very successful as some seeds where not viable and did not germinate. It is suggested that the above experiment be repeated using a lesser number of species, as follows:

- Native species of high grazing value, such species could be perennials or annuals. The suggested species are: *Plantago sp, Helianthemun lipii, Deverra torutosa, Cenchrus ciliaris*, and *Panicum turgidum*.
- Five native shrub species of ecological value in soil conservation, such species could include: *Thymeleae hirsute, Lygos retama, Gymnocarpus decandrum, Anabasis articulate* and *Asphodelus ramosus*.

Results of the repeated experiment showed that generally the percentage of seeds germinating in Petri dishes were notably higher than those germinated in pots. Germination on filter papers was rapid and notably higher, completed in 2–5 days. However small seeded plants emerged radicles earlier than large seeded plants. No difference was noted when the soil mix was added except that the capacity of the soil mix to retain water would mean more water in the soil when these plants are cultivated in their natural habitats. It may be worth mentioning that the germination percentages of the tested species are highly promising, enough to consider these plants for any rehabilitation programs (e.g. *Peganum harmala, Asphodelus microcarpus and Hyoscyamus muticus*). Add to this their ecological values as a source for livestock fodder (e.g *Panicum turgidum* and *Asphodelus microcarpus*), medicinal purposes (e.g *Peganum harmala, Salvia lanigera* and *Hyoscyamus muticus*) and for sand fixation (e.g *Retama raetam*). Some

Species	Treatment	Germination (%)	Reference
Hyoscyamus muticus	Cold temperature 3–5°C for three days	95	SUMAMAD (2005)
Ononis vaginalis	Cold temperature 3–5°C for 48 hrs soaking seeds in distilled water	97 70	present study Bidak (2003)
Peganum harmala	Cold temperature 3–5°C for 24 hrs	98	SUMAMAD (2005)
Deverra tortousa	Cold temperature 3–5°C for a week	41	SUMAMAD (2005)
Panicum turgidum	High temperature 25–42°C	72	Kabiel (2001)
Plantago ovata	Soaking seeds in distilled water for 24 hrs	52	Bidak (2003
Salvia lanigera	Cold temperature 3–5°C for a week	63	
Asphodelus microcarpus	1) Temperature ranging from 10°C to 25°C	> 90.0	
	2) In light	96.0	Hilmy (1971)
	3) Cold temperature 3–5°C for a week) complete darkness	94.0 97	SUMAMAD (2005)
Thymelaea hirsuta	1) Treating seeds with 95% H_2SO_4 for Mechanical scarification then treating seeds with 95% H_2SO_4 for 10 min. and GA3 for 24 hrs.	42.0 52	Shaltout and El-Shourbagy (1989)
	2) Mechanical scarification then treating seeds with 95% H_2SO_4 for 10 min.	24.0	
	3) Treating seeds with 95% H_2SO_4 for 10 min. and seeds subjected to constantly 15°C.	24.0	SUMAMAD (2005)
Retama raetam	Digging micropyle. Digging micropyle then cold incubation at 3–5°C.	71.4 67	Bidak (2003)
	Cold treatment 3–5°C for a week.	47	SUMAMAD (2005)

Table 8. Treatments applied for breaking dormancy used in the laboratory experiments for some of the studied species.

Species	Germination %			
	Number of days for emergence of radicle	Petri dish	Pot	Pot with soil mix
Asphodelus microcarpu	4	95	73	68
Hyoscyamus muticus	5	97	65	65
Ononis vaginalis	4	97	88	81
Peganum harmala	3	98	79	77
Panicum turgidum	5	72	68	60
Retama raetam	8	47	32	-
Deverra tortousa	8	41	-	-
Thymelaea hirsuta	3	52	-	-
Plantago ovata	5	52	-	-
Salvia lanigera	5	63	34	40

Table 9. Germination percentages and number of days for emergence of radicle.

of the tested species need further experimentation and germination trials to obtain better results for cultivation in their natural habitats (e.g. *Deverra tortousa, Thymelaea hirsute*, and *Plantago ovata*). However, some plants exhibit varied germination percentages with different germination times as well as different treatments (e.g. *Retama raetam* and *Ononis vaginalis*).

The treatments applied for breaking the dormancy in the germination experiments is shown in Table 8 while Table 9 shows the germination percentages and number of days for the radicle to emerge.

7.4 Standing crop and phytomass

Three major habitats (non-saline depression, ridge, and inland plateau) are used for grazing in OBR, with primary productivity attributed to 21 perennial species and 9 annuals recorded in the three habitats. The aboveground phytomass of perennial herbs in the different habitats ranged between 123 and 390 Kg/ha; between 70 and 1893 kg/ha for the perennial sub-shrubs; between 1698 and 4756 kg/ha for shrubs; and between 7 and 17 kg/ha for annual species. The largest proportion of aboveground to belowground phytomass was attributed to woody species.

Heneidy (1992) reported that the annual aboveground dry matter production of the rangeland in the Omayed area in the different habitats (maximum values in different seasons) was about 2,833 kg/ha in the non-saline depression, 1448 kg/ha in the ridge, and 4416 kg/ha on the inland plateau habitats. In general, the annual average of aboveground dry matter production in the entire study area was about 3016 kg/ha (using the relative contribution of each habitat to the total grazing area), most of which is invested in the ligneous structure of the range.
The calculation on rainfall basis (long-term average of 150 mm/yr) results in a rain use efficiency of about 20 kg/ha/mm rainfall. The annual production is based on standing aboveground phytomass of about 7268 kg/ha, and belowground phytomass of about 6183 kg/ha. This demonstrates the higher variations experienced by the aboveground biomass compared with those of underground biomass – a characteristic feature of desert vegetation. The vegetation components of the sub-shrubs, the perennial herbs and annuals produce about 868 kg/

ha/yr in the non-saline depression, 413 kg/ha/yr on the ridge, and 872 kg/ha/yr on the inland plateau. Thus their average annual production in the study area is approximately 787 kg/ha/yr. On average shrubs contribute the largest percentage (74%) of the total annual productivity. In the three habitats of the study area, shrubby species have the highest phytomass of new-growth and apparently of the parts accessible to grazing animals.

7.5 Water Conservation

7.5.1 Water Quality Assessment

The results of the water analysis indicate that all the water samples are nearly neutral to slightly alkaline whereas the total dissolved solids vary according to the source of water. Water from cisterns have the lowest salinities ranging from 96 to 186 mg/l. Groundwater samples from the northern part of OBR have salinities ranging from 1216 to 5,760 mg/l. The salinity of the water pipeline in the OBR is 832 mg/l, whereas the stored tap water in Omayed village is 1216 mg/l while salinities of groundwater from the Moghra Oasis range between 2,368 to 3,200 mg/l.

According to TDS (total dissolved solids) values of the collected samples, it is clear that the TDS of all the groundwater samples and the stored tap water exceeded WHO guidelines (1,000 mg/l). However, water from the pipeline has a TDS less than 1,000 mg/l. Water samples from cisterns have low TDS values but with some increase of nitrate content attributed to the effect of the grazing animal lots that are in continuous movement around the cisterns, which are essentially used for livestock consumption. Cistern waters, in general, pose no problem to livestock whereas groundwater can vary from moderate to poor quality. With regard to EC (electrical conductivity), the OBR water samples have a wide EC range and are thus classified from suitable to unsuitable for irrigation purposes. Water with <700 µS/cm are considered suitable for irrigation purposes while those with EC ranging between 700 and 3,000 µS/cm are only moderately suitable, and EC of >3,000 µS/cm are unsuitable. According to this classification, all waters in the cisterns are suitable for irrigation purposes. El-Hammam canal and the pipeline waters are moderately suitable. The treated wastewater is also moderately suitable based on salinity value, but detailed water analysis is needed for complete assessment. Groundwater from the northern part of the OBR range from moderately suitable to unsuitable, while groundwater of the Moghra Oasis is unsuitable for irrigation purposes.

According to the SAR (sodium adsorption ratio) values for the collected water OBR samples, it is clear that some groundwater samples with high salinities also have high SAR values, which indicate medium to high sodium hazard (good to fair for irrigation). However, water samples with low sodium hazard are excellent for irrigation. Another miscellaneous problem includes pH; pH values for water normally fall within the 6.5 to 8.4 range, and if outside this range may indicate a potential problem. The majority of water samples from OBR have pH values that fall between these limits indicating that the different water resources have a suitable pH.

7.5.2 Rainwater harvesting

In the Omayed Biosphere Reserve, rainfall occurs during the winter season (from October to March). The total annual rainfall recorded in 2000 and 2001 was 180 and 142 mm, respectively. The mean value of these two years, which will be used in calculating the total amount of rainwater that can be collected per year, is 161 mm. The average roof area (catchment) of the houses is 10 m x 10 m =100 m^2. Assuming an efficiency of the collecting system of about 75%, the amount of rainwater that can be collected per year from the roof is equal to 161/1,000 m x 100 m^2 x 75/100 = 12.08 m^3 (See also section 5.5.2).

7.5.3 Roman Cisterns Rehabilitation

According to the above criteria, and with the aid of field observation and water analysis, cisterns in certain areas in OBR were rehabilitated.

7.5.4 Solar water desalination

The plan of solar desalination implementation is presented in Figure 12 below.

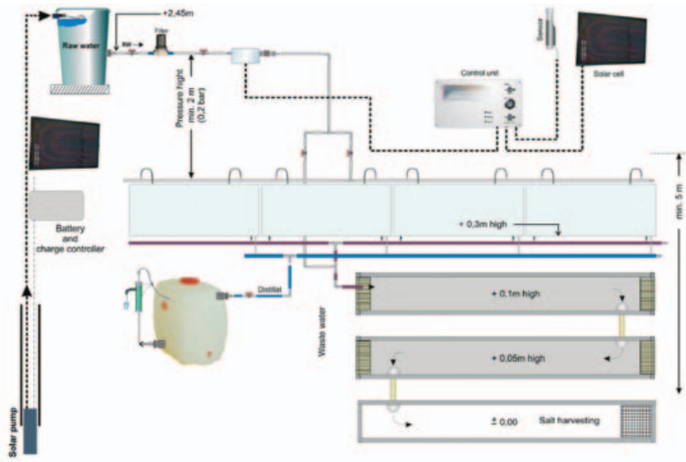

Figure 12. Plan of the solar desalination plant.

As the cells produce 6–8 litres of distillate per m^2/day, four cells with a total surface of 10m^2 should deliver 60–80 litres/day. The cells distil 50% of the raw water producing the same quantity of brine; 120–160 litres/day of raw water is needed to produce distilled water and brine at a rate of 6–8 litres of distillate per m^2/day. A flat pond evaporates about 6–10 litres of water per m^2/day, 10 m^2 should be enough to evaporate the rest of the brine. Products are as follows:

Raw water = 160 litres/day
4 cells (10 m^2) distil 50%, the rest is brine = 80 litres/day
2 stills (20 m^2) distil 60 litres/day, the rest is brine = 20 litres/day

After the initial reaction of disbelief felt by the Bedouin community, they are now convinced that these units will actually improve their lives. They are becoming aware of the link between diarrhoea and infected drinking water and the importance of clean drinking water especially for children (Figure 13). The production rate of distillate settled to about 100–120 litres per day, depending on sunlight exposure. Even on cloudy days there is enough water to provide at least five families (40–50 persons) with clean drinking water.

Figure 13. The solar water distillation panels provide drinking water for the benefit of the local community.

7.5.5 Saving irrigation water by cultivation of drought-tolerant crops

The experiment using the new cultivator proved to be successful, and the wheat grains emerged with an almost 100% success rate. However, the production level observed was relatively lower than the cultivator used in their lands. It was therefore recommended to use this wheat grain in rain-fed farms since it requires a low water supply for irrigation, and production could be used as fodder in animal husbandry. This recommendation was accepted by the local community as they preferred to use wheat cultivars already used in the irrigated farms. It is worth mentioning that the introduction of fresh-water from the new supplementary irrigation canal has enhanced the cultivation of annual crops and vegeta-bles in OBR. The irrigation system in use and currently spreading is mostly drip irrigation. The land in OBR is transforming into agricultural land as a result of the vast reclamation activities currently taking place.

The use of soil conditioner in water conservation: results in the table below show that soil conditioner consider-ably increased the available water capacity of the sandy soil revealing an increase of 21.5 % for course sand and 32.8 % for fine sand. The optimum amount of soil condi-tioner was found to be 8 g/kg soil. The water holding capacity of soil is calculated by summing up the capacity of each layer in the root zone.

8. Recommendations and conclusions for sustainable dryland management

8.1 Dryland valuation

In order to make better decisions as regards the use and management of ecosystem services, their importance to human society should first be assessed. The importance or 'value' of an ecosystem is viewed and expressed differ-ently depending on cultural conceptions, philosophical views, schools of thought, and discipline studied. 'Valua-tion' is defined by the Millennium Ecosystem Assessment (2003) as "the process of expressing a value for a partic-ular good or service in terms of something that can be counted, often money, but also through methods and measures from other disci-plines (sociology, ecology and so on)".

Because of the many services and multiple val-ues of ecosystems, many different stakeholders are involved in ecosystem use, often leading to con-flicting interests and the over-exploitation of some services (e.g. fisheries or waste disposal) at the expense of others (e.g. biodi-versity conservation and flood-control). In addition, there are many structural shortcomings in economic accounting and decision-making proce-dures leading to incomplete cost-benefit analysis of planned inter-ventions in many ecosystems. As a result, most natural ecosystems are still undervalued and over-used: in 1999,

Textural class	Available water capacity (in/foot)	Saturation (in/foot)
Course sand	0.25–0.75	5.2
Course sand with conditioner	1.00–1.25	5.8
Fine sand	0.75–1.00	5.2
Fine sand with conditioner	1.50–2.00	6.1

Table 14. Available water capacity (in/foot) for sandy soil with and without soil conditioner.

84% of Ramsar-listed wetlands had undergone or were threatened by ecological change, mainly caused by drainage for agriculture, settlement and urbanization, pollution, and hunting, and it has been estimated that in some locations 50% of wetlands have been lost since 1900 (Finlayson *et al*. 2005).

There are three situations in which it is particularly important to carry out valuation studies. These are:
1. Assessment of Total Economic Value (TEV)
2. Trade-off Analysis
3. Impact Assessment

Results from studies on the total value of ecosystems can help to compensate those people who suffered losses (loss of 'value') due to a given activity, and they can provide information to include 'externali-ties' in the economic production process (de Groot *et al*, 2006).

8.2 Indicators for determining (sustainable) use of dryland services in OBR

Ecosystem services in OBR can be divided into two main categories: environmental services and economic goods, and are considered below:

Biodiversity conservation: One of the main services of OBR is its role in conserving biodiversity resources (in terms of habitat and species diversity). This area is efficient in the sense that it encompasses a sequence of interdependent habitats in a relatively small area ranging from marine waters, sandy beaches, and coastal calcareous sand dunes. Some of the habitats are efficient in terms of water storage (e.g. coastal sand dunes and the depressions in between ridges as a result of run-off in addition to rainfall). Many plants play an important role in preventing soil erosion, increasing soil deposition, and improving drainage of the lowlands. These include species that form the phytogenic mounds, e.g. *Ammophila arenaria, Liomoniastrum monopetalum* and A*rtemisia monosermum.*

The potential and actual economic uses of the wild plants in northwestern Egypt are assessed on three bases: field observations, information collected from local inhabitants in related regions, and literature review. They are classified into seven major categories: grazing, human food, medicinal use, timber, fuel wood, charcoal, and other uses. The continuous use of these plants imposes considerable pressure on the naturally growing plants in many of the habitats in the western desert. In such habitats, the rate of exploitation is greater than the rate of establishment of new stands of collected plants. This undoubtedly has consequences affecting the components of the environment including biodiversity. Today many plants face extinction or severe genetic loss but detailed information is lacking. For the majority of endangered plant species no conservation action has been taken.

Economic important species: 129 species (78 perennials and 51 annuals) possess at least one economic use either potential or actual. They represent 51.4% of the total recorded species. Grazing, medicinal and human food uses are the most common while timber use is not indicated in this area. Twenty-two of these species are considered as multipurpose species because they have several economic uses that include:

a. *Grazing*: domestic and wild animals can graze and browse 94 of the species growing in this region (72.9% of the total economic species). The high palatable species in this area are *Echiochilon fruticosum, Plantago albicans, Stipa lagascae, Deverra tortuosa, Helianthemum lippii, Artemisia herba-alba, Althaea ludwigii, Malva parviflora* and *Gymnocarpos decanderum* (El-Kady 1987, Boulos 1989).
b. *Fuel*: almost all desert woody perennials are subject to removal for fuel. The local inhabitants mostly use the dry plant parts while travellers, workers, or other transients remove green plants when they cannot find

dry ones. Most shrubs are cut and harvested for fuel and include: *Anabasis articulata, Thymelaea hirsuta, Echiochilon fruticosum, Gymnocarpos decander* and *Lycium europaeum* (El-Kady 1987).

c. *Medicinal use*: the list of medicinal plants in desert areas is lengthy. Examples of these plants are: *Artemisia herba-alba* is widely used as an anthelmintic in folk medicine, a decoction of *Herniaria hirsuta* is used for sore throats, and boiled *Emex spinosa* leaf is used in the relief of dyspepsia, biliousness and to stimulate appetite. Seeds of *Malva parviflora* are used as a demulcent in coughs and bladder ulcers, *Sonchus oleraceus* is reported to be useful for liver complaints, jaundice and as a blood purifier, while *Salsola kali* is used as an anthelmintic, emmenagogic, diuretic and cathartic.
d. *Human food*: fruits, flowers or/and vegetative parts of 33 species in this region are eaten by local inhabitants. Malva parviflora is a popular pot herb in Egypt. *Deverra tortuosa* and *Sonchus oleraceus* are eaten as a salad. *Colchicum ritchii* is used as one of the numerous ingredients added to the beverage prepared from the rhizomes of 'Moghat' (*Glossostemon bruguieri*), usually offered as a tonic on birth occasions in Egypt. Some mammals such as rats and rabbits and some birds such as quail are eaten.
e. Traditional uses (e.g. rope making using *Thymelaea hirsuta*).

The following goods are of minor representation and characterized by the complete or partial loss of natural vegetation such as rainfed agriculture (9 %), military uses (6 %), quarries and fragmentary uses (2.6 %). Thousands of local tourists already visit the area annually for recreational purposes (3.4 %), spending the summer months in the vicinity of OBR, and more pass through it on their way to resorts in Marsa Matruh. The OBR could become an additional attraction for these visitors. In addition to the previously mentioned services, the region offers educational and scientific research services. This region receives many scientific visits from students of different universities for the many ecological aspects it demonstrates (e.g. primary succession on sand dunes, rocks and salt marshes). In addition, many research MSc. and PhD programs have been carried out in OBR, and many papers have been published as a result.

The saline and non-saline depressions, inland ridges, limestone plateau, inland siliceous sand formations (flats, mounds and dunes) and human-made rainfed farms all support diverse flora and fauna (approx. 250 flowering plants, 300 invertebrates, 200 avifauna, 30 herpetofauna and 28 mammals). Some of these biota are endemic and/or threatened.

Economical plants: 17 wild plant species in OBR are used as sources of fuel wood for domestic use, while 13 species are considered as sources for oil and soup production. There are 8 species used in flower beds and gardens, 3 species used for fencing and roofing purposes, and 4 species are edible. More than 27 plant species in the region are rated as having high grazing value, 7 more species are rated with intermediate grazing value, and 10 species are rated most palatable by camels in particular.

Ecological value: the role of plant species in the different habitats of OBR varies with habitat characteristics. This includes the following examples:

a) 9 species help in the fixation of mobile soil and in building up soil layers;
b) 13 species are effective in settling air-borne sand particle during storms;
c) 6 species of special growth forms (creepers and prostrates) protect the soil surface and retain its moisture content;
d) 11 species are valuable for other vulnerable delicate species in terms of protection or providing refuge for some others; and,

e) 7 species are characterized by their resistance or tolerance of high salinity levels.

Endangered and threatened species: 17 plant species are rated as endangered or threatened. Moreover, the entire sand dunes habitat including their characteristic species is highly threatened due to ongoing land conversion activities and the resulting fragmentation of the habitat.

8.3 Conclusions

8.3.1 Rural development in the Omayed Biosphere Reserve: scenarios and consequences

As mentioned above, the current ecological conditions in OBR and its hinterland indicate that the present level of human pressure is leading to significant environmental deterioration that calls for an urgent plan for conservation and development. The consequences of different scenarios are:

a) Impacts on main ecological features.
b) Effects on the future of resources.
c) Results concerning the socio-economic situation of land-users.

The proposed model simulates variation trends in ecological conditions as a result of different land uses.

8.3.1.1 Level 1

Full protection: although unrealistic is proposed for a comparison of economic values with other scenarios. It is assumed that such a scenario could be implemented in the core areas of the biosphere reserve and would call for the establishment of more core areas as there is only one core area (only 1km^2), although currently functioning it is not sufficiently large for such a scenario. The consequences of this scenario are such that each unit would evolve according to its regenerative capacity. Units where agricultural practices are suddenly abandoned are progressively invaded by plants of the type which gradually rebuild the native vegetation cover corresponding to the ecological conditions.

8.3.1.2 Level 2

Rangeland development and limitation of ploughed fields: this scenario implies that annual crops cultivation and tree plantations would be limited to suitable areas only. This scenario also implies the adjustment of stocking rate on the ranges to the present grazing capacity so as to ensure the recovery of plant cover by rotation in depleted areas. In this case, it becomes necessary to have supplementary feed during the transitional period preceding the complete restoration of ranges. The consequences of such a scenario, is the biological recovery and satisfactory control of degradation. This aspect is rarely taken into consideration by economists.

8.3.1.3 Level 3

Continuation of present practices and maintenance of present land-use system: current practices indicate that with the present system of annual crop cultivation and tree plantation, yields will remain low. Areas used for grazing will be gradually overgrazed and will decrease in area. Continuation of present practices means more ploughing for cropping and an extension of orchards and annual cropping of cereal and vegetables, particularly after the extension of the supplementary irrigation canal from the Nile. This scenario also means an increase in the number of animals and no rangeland management planning (e.g. limitation of stocking rate according to the level of production of rangelands). Although this scenario is the most probable, it will result in immediate limitations for land use. For instance, the harvesting of large areas of low yield cereals by hand is a bottleneck as it will be difficult at present to visualize the introduction of mechanized harvesting in such low yield conditions. A constant decrease of areas used for grazing is associated with permanent overgrazing during certain periods. An extension of cereal and vegetable farming and fig plantation, in addition to overgrazing and severe uprooting, increases the degradation processes.

8.3.1.4 Level 4

Intensification of present practices: this scenario forecasts that the recent rapid expansion of orchards for economical reasons will further increase over the next twenty five years such that the socio-demographic conditions will necessitate an extension of cropping (with the possibility of mechanization) for human and animal consumption. The consequences of this scenario include possible misuses of the area with the mechanization of ploughing and other agricultural practices, and the creation of watering points without limitations to herd size of herd or grazing period.

8.3.1.5 Level 5

Extension of land reclamation using the supplementary irrigation canal as a source of irrigation water: such a development scenario must be evaluated according to the environmental potential and availability of the local labour force. This scenario may provide a possibility for regional development if good yields are attempted for cereals and various feeder crops, and if a limitation of animal stocking rates on rangelands is achieved. The environmental conditions of the above must be carefully considered in order to avoid salinization and water logging. The consequences of this scenario include the heavy investments needed to introduce such a level of human pressure. This system will obtain similar results as those of level 2 but with higher agricultural production due to the extension of irrigation.

8.3.2 Geodatabase

It was found that the local community was able to geographically locate zones with great accuracy on a base map as well as on a satellite images, as well as by drawing free-hand on a white sheet. The size (surface area) they allocated to a certain location depended directly on the importance of this location on their livelihood. The satellite imagery was a very valuable tool used to delineate areas of land degradation, which was subsequently shown to the local community leading to a better appreciation of the problems and its effects.

8.3.3 Soil degradation

With regard to the field surveys on soils, which are closely related to satellite image analysis (classes 4 and 5), it was generally observed that the sparseness of the vegetation cover together with the harsh climate can cause extensive soil erosion in almost all the OBR habitats. The significant potential agents of soil degradation are explained below:

Water erosion: in areas of the OBR where rainfall is low to medium, vegetation cover is usually low; soil erodibility is often high, especially in sandy loam, sandy clay loam and silty loam textured soils, which represent the majority of soils in the area and particularly around Khashm el Eish ridge and Moghra.

Soil erosion by wind and sedimentation: soil erosion by wind as well as seedlings buried under wind blown sediments was clearly observed. Areas of patchy wind sedimentation, which when not disturbed by cropping often take the shape of hummocky lands that generally increase biological productivity and increase soil thickness and fertility.

Soil fertility decline: comprising the degradation of physical, biological and chemical soil properties. It is not simply a problem of nutrient deficiency but also of overgrazing, the uprooting of native species in important habitats e.g. nonsaline depressions and salinization due to irrigated cultivation.

Increased stoniness and rock cover of the land: this phenomenon was clearly demonstrated in the inland plateau and the OBR hinterland. It is usually associated with extreme levels of soil erosion causing exhumation of stones and rocks.

8.3.4 Land evaluation of OBR

The results indicated that 61% of the soils in the study area were grade V i.e. this soil type is unsuitable for agriculture under current conditions but it can be elevated to grade III or slightly suitable for some agricultural practices. In addition, about 20% of the soils were grade IV meaning that this soil type is almost unsuitable for agriculture under current conditions, while 19 % of the soils were grade III meaning that this soil type is slightly suitable and can be increased to grade II or suitable for specific uses of crops by some agricultural practices. Therefore, 19 % of the total area can be considered potentially productive, which covers a considerably large area.

8.3.5 Propagation of endangered and multipurpose species for rehabilitation purposes

Rehabilitation involves the propagation of multipurpose species that naturally exist in the north coastal desert of Egypt. Propagation would include identification and collection of propagating material (e.g. seeds, other vegetative propagules, perennating organs), culturing and then reintroducing the species for rehabilitation purposes. Ten of the most commonly usable perennial species are selected during this phase to test their germination and possibilities for propagation as a first step towards rehabilitation. Generally, the germination percentage of seeds germinated in Petri dishes were notably higher than those germinated in pots. Germination on filter papers was rapid, completed in 2–5 days, and notably higher. However, radicles emerged from small seeded plants earlier than from large seeded plants. No difference was noticed when the soil conditioner mixture was added.

8.3.6 Productivity and standing crop phytomass

In general, the total phytomass of new growth is highest in the inland plateau habitat and lowest in the ridge habitat. The total seasonal contribution of new growth by the life-forms differs greatly with habitat and season. For example, the highest contribution by perennial herbs in all the habitats was attained during winter and spring (13 % and 10.9 % in the non-saline depressions, 12.7 % and 13.5 % on the ridges, and 9.5 % and 8.3 % on the inland plateau, respectively). On the other hand, the maximum contribution by most sub-shrubs was attained during spring. The contribution by sub-shrubs in non-saline depression, ridge and inland plateau habitats in spring was 15 %, 14.5% and 10.1%, respectively. In general, the nutritive value of forage decreases with advancing plant maturity. This is mainly due to the decrease in protein content and the associated increase in the fibrous components and general lignification.

8.3.7 Water resources

In OBR and its hinterland, like any other place in the world, water is a vital source of life. The provision of water relies on soil (storage, transportation, filtering, mineral composition, taste, and evaporation) and vegetation (storage, transportation, filtering, evapotranspiration and rainfall susceptibility). According to climatic data, the sequence of water balance is divided into two periods. The first is from December to February when precipitation barely meets water requirements expressed by evapotranspiration with no moisture surplus as any excess water is used up naturally to recharge the dry soil through infiltration. The second period is the dry season which extends from February to November when water requirements greatly exceed precipitation and the actual evapotranspiration falls well below the potential, resulting in severe moisture deficiency.

8.3.8 Water quality

The physio-chemical characteristics of the water samples vary according to location, topography, other climatic and microclimatic factors as well as anthropogenic effects. The groundwater in the northern slope of the OBR showed a higher content of total dissolved solids and electric conductivity (EC) relative to the water samples collected from cisterns. This is mainly because groundwater is affected by mixing with salt water due to over pumping. The pH of all the samples varied from neutral to alkaline. Water collected from cisterns are ultra fresh as it originates from rainwater falling on the catchments area of the cistern and dissolving soil soluble salts, and thus its salt content is relatively low. Water analysis showed that according to TDS values of the samples collected, it is clear that TDS of all groundwater samples and the stored tap water exceeded the WHO guideline (1,000 mg/l). However, water from the pipeline has TDS less than 1,000 mg/l. Cistern waters in general cause no problems to livestock whereas groundwater varies from moderate to poor.

8.3.8.1 Management alternatives for water use

There are several management alternatives available to prevent or reduce salinity problems. The first is related to the choice of crop to be cultivated. Crops vary greatly in their salt tolerance and therefore the suitability of relatively salty water for irrigation will also vary depending on the crop. The FAO guidelines for crop tolerance criteria can be used to select crops to match the quality of the available water supply and the expected degree of soil salinity to which the crop will be exposed. These guidelines list tolerances of several representative field, vegetable, forage and fruit crops to both the salinity of the water applied or the irrigation water, and to the salinity of the soil. The second involves the application of extra water for leaching that is normally used by good cultivators and farmers to control salt accumulation. However, the presence of a shallow water table and the absence of a drainage system in the study area make the leaching process increasingly difficult or even impossible. If salts are leached a shallow water table may quickly allow re-salinization to occur as salty subsurface waters rise to the soil surface where the water evaporates and leaves salts behind to accumulate again in the crop-rooting zone.

According to SAR values for the collected water samples from the OBR, it is clear that some groundwater samples with high salinities also have high SAR values which indicate medium to high sodium hazard (good to fair for irrigation). Most water samples show low sodium hazard (excellent for irrigation).

Groundwater in the region occurs under both artesian and non-artesian conditions, however, all the ground water available for agricultural and domestic uses occur in relatively shallow non-artesian aquifers. Large quantities of groundwater are deeply seated in rocks ranging in age from Cretaceous to Miocene, but water is brackish or highly saline. Groundwater in OBR is available for agricultural and domestic uses. The main resources are:

1. Cisterns used for animal consumption though only a few are in operation.
2. Pipeline of the national water services used to supply fresh drinking water for people and animals.
3. Surface runoff from Khashm El-Eish to the non-saline depression, which requires good management to make full use of the quantities received.

8.3.9 Water Conservation

8.3.9.1 Rain water harvesting

Awlad Gebreel village annually spends about L.E. 425,955 (~ USD 78,000) on water, which could be reduced by L.E. 10,570 (~ USD 2,000) by introducing rainwater harvesting techniques such as from roofs. An additional source of drinking water can be set up in this village using solar energy in the desalination of salty raw water extracted from wells that are widespread in the area.

8.3.9.2 Roman cisterns rehabilitation

The EU-sponsored Medwet coast project contributed to the rehabilitation of about eleven Roman cisterns as well as the establishment of a huge water catchment reservoir in the Omayed area. The SUMAMAD water conservation activities therefore concentrated on solar water desalination.

8.3.9.3 Solar water desalination

The solar desalination cells have proved to be a practical solution in producing safe drinking water. Minor maintenance is required and can be provided by the end users even if they have received little education. It is recommend placing one or two units on each family house and to specifically train women on how to use it; as the freshwater tank will be placed inside the kitchen it can be immediately detected if the supply stops. Every family would be responsible for their own drinking water supply and the measures to be taken if it stops; measures include filling the tank with a bucket should the pump fail to work. The provision of clean drinking water is also recommended to houses that have trained personnel and therefore the means to maintain their own system, and to provide some larger plants (up to 10 units; 200 litres/day) to the other families so that they can collect water using jerrycans. Ideal places for them would be schools and other public buildings.

8.3.9.4 Saving irrigation water by cultivation of drought-tolerant crops

It was noted that the production of drought-tolerant crops was low compared to other crops used by the farmer on his land. It was therefore recommended that this wheat grain be used in rainfed farms as it requires a low water supply for irrigation and the production used as fodder for animal husbandry. This recommendation was accepted by the local community as they preferred to use the wheat cultivars they already use in irrigated farms.

8.3.9.5 Using soil conditioner for water conservation

The tested soil conditioner is useful for sandy soils to increase their available water capacity. It is therefore recommended soil conditioner be applied to agricultural crops in the coastal sandy soils where annual crops e.g. vegetables, wheat and barely as well as orchards of figs, olives and almond could be planted without depleting the soil from its nutrients, and thereby conserving every drop of water including dew and rainwater. However, a cost benefit analysis should be conveyed to assess the feasibility of applying soil conditioner on a large scale.

9. National Seminars

1. A workshop on site assessment methodology for Omayed Biosphere Reserve and its hinterland took place on 23 October 2003 and was attended by 26 participants. The objective of this workshop was principally to reach consensus on the assessment methodology adopted in project implementation.

   The scientific team of the project each delivered a presentation on the status of the resources under investigation, the stresses on the particular resources, a description of traditional knowledge, and an explanation of the suggested methodology and the suitability of its implementation according to the nature of OBR and its hinterland.

   The workshop ended with a comprehensive open discussion among the experts on the methodology adopted, and all the remarks and suggestions of the experts were noted and added to the methodology. The workshop concluded with satisfaction and the approval of the methodology adopted, and the efforts of the scientific team of the project were commended.

2. In 2003 a Bedouin open discussion took place and was attended by 63 participants. The workshop included open discussions with the local inhabitants and their administrative bodies in order to garner their perspective on the uses of the natural resources in the OBR and its hinterland: the stresses posed on these resources from their point of view, the ways and means of dealing with these resources according to their traditional knowledge, the role of women in the Bedouin family, the provision of social services (educa-

tion, health, potable water, etc), and their awareness on the major environmental problems they face i.e. water scarcity, land degradation due to overgrazing and wood cutting, habitat fragmentation and biodiversity loss.

3. A national workshop for MAB National Committee members and the Environmental Affairs agency took place in 2004 and was attended by 20 participants. Members commended the activities of SUMAMAD and directed the attention of the SUMAMAD team about the activities of the MedWet Coast Project of the EU, and how best to integrate the activities of both these projects in OBR. Members also confirmed the importance of Moghra and suggested the use of the project results to extend OBR to include Moghra Oasis as an additional core area.

4. National workshops for women took place in 2005 and were attended by 24 participants including members of the UNESCO National Commission. The workshops introduced the importance of income-generating activities for women, their role in conserving resources, as well as training on sewing Bedouin clothes producing good quality garments for sale.

5. A training workshop of the SUMAMAD team took place in March 2006 and was attended by five participants. The course included the following items:
- The different types of satellite images, their properties (spectral, spatial, temporal and radiometric resolutions) and their potential uses.
- The selection of the appropriate digital image processing procedures (enhancements) for different purposes.
- The introduction to ERDAS/Imagine software and exercises on image display, raster/vector overlay.
- Image classification (supervised and unsupervised), onscreen digitization, and assessment of land cover classes with accuracy assessments.
- Change detection techniques and its accuracy.

6. Training of Bedouins on water conservation and solar water desalination and the properties of safe drinking water took place in April 2006 and was attended by 47 participants. The main questions asked by the locals were on the procedures of maintaining the solar desalination units and on ways and means of enlarging their capacity of production of freshwater. The maintenance procedures were explained in detail and even demonstrated to the children, who were very excited to show their contribution to the process. The local communities were promised by the SUMAMAD staff that all efforts to extend the solar water desalinization project will be mobilized so as to find ways and means to funding these units, under the proviso that the communities demonstrate their cooperation to care for and maintain the solar units.

7. A national workshop and the celebration of the Year of Deserts and Desertification took place on 29 June 2006 and was attended by thirty participants. The success of the SUMAMAD sites for solar desalination implementation was seen as further proof for expanded development and production at the national level. The units will be introduced to governorates in the western and eastern desert e.g. Matruh on the west and Sinai on the east. It is anticipated that these units will contribute to the provision of fresh drinking water in these governorates.

8. A workshop reviewing the SUMAMAD activities, from the start of the project to the present day as well as future activities, took place on 17th July 2007 with thirty invited participants.

10. Research institution and team composition

10.1 Research Institution

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As for year 2005 and 2006, with the exclusion of Dr. Sanna Mabrouk, and the addition of:

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11. Publications as a result of SUMAMAD

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4 Gareh Bygone Plain

Islamic Republic of Iran

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Introduction

The forced sedentarization of nomads in the 1930s in the Gareh Bygone Plain (GBP) in southern I.R. of Iran devastated a 6,000 ha sandy scrubland which was previously teeming with wildlife. Overgrazing, fuelwood collection, senseless hunting and worst of all, application of inappropriate technologies such as moldboard ploughs and pumps resulted in a desert more reminiscent of a moonscape. The water table receded 10 m in 12 years. Salt water intrusion into a shallow alluvial aquifer compounded the water shortage problem. Soil salinization was an outcome of irrigation with saline waters. These left most of the sedentarized trekking nomads-turned-irrigation farmers without livelihoods.

Daily sandstorms, mainly from April to September, clogged the country roads and irrigation ditches, filled the yards of *adobe* houses, and caused respiratory diseases tens of kilometers downwind from the GBP. These maladies resulted in the migration of a large number of inhabitants of the plain to Fasa and other neighboring towns and cities. They exchanged subsistence farming to below subsistence urban living. Shanty towns have sprawled on the outskirts of such communities. As these environmental refugees lacked the marketable skills in their new dwellings, many of them resorted to illegal arms trading, ammunition and narcotics; those more fortunate earned low wages as manual laborers. Security among the population began to collapse. Furthermore, the migrants were an additional burden to the municipalities already overtaxed with services required by the local residents.

A few hardy souls who opted to stay eked out a living from 16 low yielding wells, which could be operated between 1 and 20 hours per day. Loan sharks were on the prowl buying future harvests at very low prices. Potable water carried inside goatskin bags was hauled over long distances and became a daily chore for women and youngsters. This resulted in back pain and miscarriages among the women, and lower school attendance among the children.

Thus the stabilization of the moving sand and the provision of domestic and irrigation water were prerequisites to stemming the cityward tide of migration while enticing the migrants to return home; aquifer management provided the panacea.

1. Main dryland challenges

Achieving success against many technical, natural, financial, social and bureaucratic obstacles at the Kowsar Floodwater Spreading and Aquifer Management Research, Training and Extension Station (KS), convinced some policy-makers to implement the Aquifer Management (AM) concept on a larger scale. Thus, the establishment of 38 research stations in different ecological zones of the I.R. Iran was mandated on 27 March 1996. As this country is endowed with about 42 million ha (mha) of coarse-grained alluvium and 6 mha of arable land underlain by potential aquifers, the mean annual wasted floodwater exceeds 50 km^3, and the implementation of the AM concept has already been planned to cover 1.5 mha during the 2006–2010 period; the artificial recharge of groundwater (ARG) systems, the linchpin of AM, may eventually cover 14 mha, harvesting 42 km^3 per annum. As this undertaking is extraordinary, capacity building of 4 million stakeholders is vital. They not only have to construct and maintain the AM systems, but they also have to learn how to optimize the use of the resources. These call for a mutual trust between technocrats and beneficiaries.

Aquitopia is an action research project in desertification control through floodwater spreading for the planned and implemented ARG in close cooperation with sedentarized trekking nomads in marginal and sub-marginal drylands. Forty young couples and thirty research scientists and technicians cooperate in establishing a 1,000 ha farm, implementing applied research, and generating income to improve their livelihoods by artificially recharging groundwater, floodwater and common irrigation farming, small livestock rearing and bee-keeping. As tail-end spreaders may receive less water in some events, provisional ownership of the fields located on spreaders are rotated in an effort to equalize the chance of operators receiving adequate floodwater.

The next phase of this project is building a green village adapted to desert living. *Aquitopia* will be a model of living with nature. The ultimate objective of this endeavor is to prove that:

Water is wealth;
Spreading water is spreading wealth; and
It is water, not oil that sustains life!

2. Environmental characteristics of the study site

(More details for this section may be found in Kowsar and Pakparvar, 2004)

2.1 Geomorphology

The debris cone formed by the Tchah Qootch (Well of Ram in Farsi language) River (28° 34' N, 53° 56'E), an ephemeral stream that drains a 171 km^3 intermountain watershed east of the GBP, is the site of our experiment. This basin was formed by the tectonic movements of the Zagro-s Mountain Ranges during the Mio-Pliocene epoch in the Agha Jari Formation (AJF). It covers only 0.35% of the Mond River Basin, and the diversion of its total flow should not therefore greatly affect the hydrology of the entire basin.

The AJF, which covers 27680 km^2 in south-southwest Iran, ranges in age from the late Miocene to the Pliocene epoch. It consists of calcareous sandstones, low weathering, gypsum–veined red marls, and grey to green siltstones. Severe erosion of the Plio–Pleistocene Bakhtyari Formation (BF), which formerly unconformably capped the AJF during the Quaternary period, has left only small, scattered patches of the BF in the Tchah Qootch Basin. The BF, which mainly consists of pebbles and cobbles of Cretaceous, Eocene, and Oligocene limestone and dark brown ferruginous cherts, has provided the bulk of the alluvium in the debris cone – the AJF has contributed the rest.

The known thickness of the alluvium ranges from practically nothing at all at the foothills to 43 m at the centre of the KS. Fine sand and gravel form the upper 12 m thickness of the alluvium, the rest consists of medium and coarse sand, gravel, and stones of different sizes, up to 40 cm in length.

The westward-flowing Tchah Qootch River has deposited the debris cone that terminates on its western extremity by the Shur (saline in Farsi) River of Jahrom (Fars Province) an effluent perennial stream that flows southward in the thalweg of the GBP. The base flow of this river, which drains the 4530 km^3 Fasa watershed, is quite saline; the electrical conductivity (EC) ranges from 6 to 45 dsm^{-1} during the year. As the general direction of the groundwater flow in the debris cone is westward, a substantial volume of water which, if not extracted from the aquifer, eventually turns saline and seeps into the Shur River of Jahrom. Although the salinity source has not yet been pinpointed, it is postulated that the dissolution of a hidden salt dome by the karstic waters, which probably discharge through a thrust fault on the western margin of the GBP, pollutes the groundwater in the area.

2.2 Hydrology: Precipitation characteristics

2.2.1 Amount

The GBP is an extremely dry place with a mean annual precipitation (MAP) of 243.3 mm and Class A pan evaporation of 3,200 mm. Temporal and spatial variations in this plain are high. The closest meteorological station to the research site is at Baba Arab, 15.7 km to the west-southwest of the KS. The meteorological station at the KS, established in 1996, has been instrumental in collecting the ten years of data. The double mass curve method was employed to correlate the data from KS with those of the Baba Arab Station (BAS). A significant correlation between the two stations (R2=0.91) indicated that we may use the BAS's rainfall data to synthesize the 1970–1995 period's missing data for the KS. The MAP for the1971–2002 period ranged from 54.5 to 556.5 mm with a mean of 243.4 and 244.6 mm for the GBP and BAS, respectively.

2.2.2 Variations

It is observed that the December–February period has the highest, and the July-August has the lowest amount of precipitation. However, as with any arid zone, there is the likelihood of convective storms in the summer as occurred in 1994 during which 31 mm of rain was registered.

2.2.3 Frequency

The recurrence interval (RI) for different periods was determined using the data from BAS, which benefits from the Hydrological Frequency Analysis (HYFA) software. Preliminary analyses revealed that Pearson type III and the gamma distribution best suit the maximum 24 hour rainfall and MAP, respectively. The MAP and the maximum 24 hour rainfall for the RI of 2–100 years were estimated. The maximum expected 24 hour rainfall over a period of 200 years is 86.3 mm. As the maximum 24 hour rainfall recorded at the KS was 90.0 mm on 3 December 1986, this rain therefore belonged to an interval of more than 200 years. The maximum annual rainfall of 556.5 mm recorded in the1992–3 hydrological year belonged to the 100 year interval.

The rainfall intensity, which is a major factor in runoff inducement, is lacking for all of the stations whose data are used in this study. However, as the AJF, which covers the basins whose floodwaters are intended for diversion towards the research site, is relatively impermeable, a lack of rainfall intensity data is of no great concern.

The minimum amount of rainfall that can initiate a flow in the Bisheh Zard Basin is 5 mm, if it occurs in less than one hour. Therefore, the collected data are still very useful in predicting flood occurrence. The maximum runoff coefficient for the AJF, which occurred on 3 December 1986, was 0.56. As the Tchah Qootch Basin is geomorphologically identical with the Bisheh Zard Basin, they may therefore be hydrologically identical too.

The coefficient of variation (CV) of 0.46 for the rainfall at the KS indicates a slim chance of receiving adequate rain every year. Therefore, the systems have to be designed and constructed in such a way as to harness the largest possible flow that is technically practicable, environmentally sound, financially viable, and socially acceptable.

2.3 Surface and Groundwater Hydrology

A few brackish seepage springs of little consequence provide the surface water used by the wildlife and some livestock. The estimated peak flow of the Tchah Qootch River with the RI of 50 and 100 years are 302 and 373 $m^{3}\,s^{-1}$, respectively.

The peak flow of the Bisheh Zard River on 3 December 1986 was 300 $m^{3}\,s^{-1}$, of which 75 $m^{3}\,s^{-1}$ were harvested in our ARG systems. Although we design the systems for the RI of 50 years, water scarcity dictates that longer intervals should be considered.

2.3.1 Groundwater

Transmissivity (T) of the alluvium, as determined by Jacob's method, is 790 m^3 per day, which is typical for a coarse-grained alluvium. Taking the width (W) of the aquifer at 3,000 m and the hydraulic gradient (i) at 0.0065, we have:

Q = WTi = 3,000 m x 790 m^2 X 0.0065=20540 m^2 day-1 = 237 litres per second (ls^{-1})

This means that if we are planning to irrigate 440 ha using 24 shallow wells over a 6-month period, our annual diversion of floodwater should be at least 4.62 million m^3, of which 80% recharges the aquifer. The maximum allowable pumping for a 12-hour period from each well is 20 ls^{-1}.

2.3.2 Water quality

The floodwater used in the ARG system is classified as sulfatic-calcic-magnesic. EC of the Tchah Qootch flow ranges 0.25–4.00 dsm^{-1}; the lower figure belongs to floodwater, the higher figure belongs to the seepage springs in summer. The EC of well water has a range of 0.58–14.0 dsm^{-1}. A possible reason for the high EC of the wells outside the influence of the ARG systems is an intrusion of saline water from a thrust fault to the SW of the ARG systems. It is only through keeping a high head in the freshwater aquifer that we can hinder the encroachment of saline water into it.

2.4 Soil formation and their characteristics

Of the five soil forming factors in the GBP, the parent material is the most important. The aridic precipitation regime and the hyperthermic temperature regime have not facilitated the physico-chemical and biological weathering. Therefore, the soils of the plain are limited to the orders Aridisols and Entisols. The presence of loose sand on the plain is due to the water erosion of the AJF sandstone, deposition of the sand in streambeds, and their subsequent transportation by wind to the settling areas.

Four physiographic units are recognized in the study area: plateaus and old alluvial fans, gravelly alluvial fans, floodplains, and piedmont alluvial plains. The soils on these units are respectively classified as Typic Haplocalcids, Typic Torriorthents, Typic Torriorthents, and Typic Haplocambids. The area intended for the ARG and irrigated agriculture is in class II, which covers 758.74 ha, and class III, which covers 1106.30 ha of the total mapped area of 2,092.74 ha.

2.5 Vegetation

Phyto-geographically, the GBP is located between two major habitats, the Irano-Turanian domain and the Persian Gulf-Oman group. *Zizyphus nummularia* Burm. F. Wighth & Arn. and *Pteropyrum aucheri* Jaub & Spach, which attain a height of 3.0 and 1.5 m respectively, are the tallest bushes on the debris cone. *Artemisia sieberi* Besser., *Atriplex leucoclada* Boiss., and *Astragalus glau-*

cacanthos Fisch. are found on the eroded soils of the GBP. Occasional, isolated bushes of *Amygdalus liciodes* Spach, *Amygdalus scoparia* Spach, and *Pistacia khinjuk* Stocks occupy hard to reach crevices; otherwise they were cut down. For more details refer to Kowsar and Pakparvar, 2004.

3. Socio-economic characteristics of the study site

The nomads and transhumants were forcibly sedentarized in the Gareh Bygone Plain, and for the most part are called Arabs; they are presumably descendants of the Muslim invaders who occupied Iran in the eighth century under the rule of Calif Omar. They have a distinct dialect, a mixture of Persian, Arabic and Turkish. These warlike nomads belong to the *Khamseh* Confederation, which was created by the *Qavam* clan of Shiraz in the middle of the nineteenth century to balance the power of the *Qashqai* Tribe (De Planhol, 1968). These free spirits were not cultivators of the land. Besides, they had been given a landscape which was mostly covered with sand. Three of the villages had low yielding qanats. The fourth was established after hand digging a well (*Tchah* in Persian) by the government (*Dowlat* in Arabic); so it was called *Tchah Dowlat*. Rahim Abad and Ahmad Abad have more fertile soils than the other two villages.

Ab means water in Persian. *Abad* means 'developed', as development in arid lands is invariably connected with water. Rahim and Ahmad were the names of the developers. Bisheh Zard (yellow meadow) took its name from the watershed in which reed turns yellow (*zard*) during drought. Bisheh Zard had to be relocated after its qanat went dry and the groundwater turned saline due to overpumping. New dwellings were constructed about 1 km to the east of the abandoned village and closer to the watershed, and at a higher level on the debris cone.

Goat is a highly prized livestock among the nomads, as this hardy animal scales rocks and crevices unreachable by sheep. In addition, it browses many sclerophyllous plants spurned by sheep. These people do not raise cattle. Transhumant nomads usually live in black tents made of goat hair. Using iron or wooden spindles, women and girls spin the hair and make yarns about 2mm thick. It is a joyful sight to see a shepherdess in a colorful costume spinning a spindle while following her herd of sheep and goats. Even some men do it. The yarns are later twisted together to make twine. Using a horizontal loom equipped with heddle and shed rods women weave the tent fabric with the twine. A pitched tent looks like a rectangular box lying on its largest side. Mats, made of rushes or light cane, are wrapped around the lower part of the tents to make them more solid and weatherproof. The lower ends of the mats are held in place by inserting them in narrow trenches filled with compacted soil. Gutters dug around tents direct runoff away from them.

These tents are not wind- and waterproof. However, as goat hair imbibes water and swells, the fabric openings therefore become smaller under rainfall and less air travels through the tent in cold winter nights. The very same fabrics covers the top of corrals or cave entrances that shelter livestock and draft animals to keep them warm in chilly weather.

Although women do most of the hard work, male domination rules the household. However, formal education might alter the situation. Now, the majority of girls attend primary and secondary schools, and some enter universities.

Water is collected in shaved, goatskin bags. Ghee (processed butter) and grape syrup are kept in unshaved goatskin bags. These versatile bags are storage houses for grains, flour, pulses, medicinal herbs and so on. Each nomad family has at least one short tail and cut-eared guard dog who warn the owner of any approaching threat, be it a wolf or burglars. Beware the person who inadvertently kills a guard dog! He/she will have to pay dearly for this infringement of unwritten law.

Nomads are very hospitable; they may even sacrifice their prized sheep or goat at the feet of a cherished guest. However, they are wary of strangers, as there are often armed rustlers who pretend to be innocent travellers. Nomads' hospitality extends to their absent guests too. As they move to a new location in their semi-annual trek, they leave some food, water and fuelwood for the next clan that replaces them the following evening.

A venerable tradition of some nomadic tribes is to name boys after strong and magnificent creatures, features or phenomena; for girls, they are named after beautiful animals, flowers, and atmospheric phenomena. Thus lion, tiger, leopard, wolf, dog, eagle, thunder, mountain summits, and rivers signify men; gazelle, crane, dove, pigeon, nightingale, rose, jasmine, breeze, dew, and rain, to name only a few, are names given to girls. Disputes arising between men are settled amicably by the elders who are called 'white bearded'; the 'white braided' settle disputes between women.

3.1 Demography

As of September 2003, there are four villages in the GBP with a total population of 2,127. The annual population growth rate, based on the latest five-year data, is 1.7%. The inward migration, although significant due to water availability, was not recorded. The outward migration in the past five years, due to drafting into the armed services and leaving for college, remains at 2.5% of the population. Population data for the GBP are as follows: Ahmad Abad, 27 households and 220 persons; Bisheh Zard, 80 households and 486 persons; Tchah Dowlat, 148 households and 801 persons; Rahim Abad, 107 households and 620 persons.

All of these villages have access to safe water, electricity, fossil fuels, radio and television programmes, school and public health facilities. Only Ahmad Abad does not have an asphalt road.

Taking the poverty level in Iran as the criterion, 68% of the households in the GBP live below the lowest standard poverty line. The rest live just above the poverty line. It is probable that 80–90% of this group (32%) descend beneath that line in difficult times.

The minimum, maximum and average annual per capita income of the villagers in the GBP for 2003 in USD purchasing power parity was: 456, 1750, and 1061 for the people below the poverty line; 1767, 7425, and 3044 for the people above the poverty line. The Human Development Index for the people of the GBP was 0.568 in 2003.

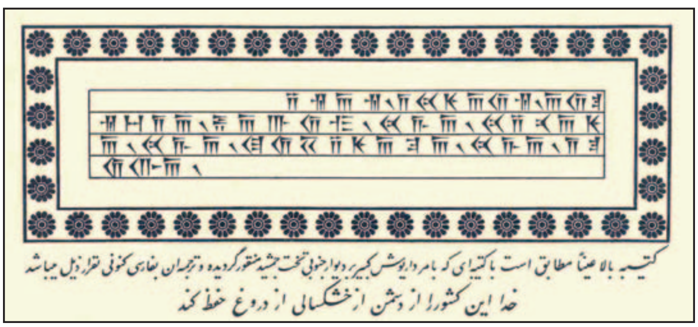
3.2 Means of earning livelihoods

Mixed farming (raising wheat, barley, cotton, sugar beets, alfalfa, tomatoes, cantaloupe, melon and watermelon, and herding sheep and goats), plus a minor amount of citrus fruits, make the bulk up the population's income. About 49.3% of the households comprise mixed farmers, 50.6% are herders, and 80% are service workers. About 29.3% raise farm and horticultural crops and herd as well; 36.0% of farmers raise horticultural crops and do service work; 37.3% are herders and service workers. However, there are many overlaps in these percentages, as men, who are the bread-winners, try their hands in many businesses even becoming common laborers as the need arises. As concerns women workers, very few in each village weave carpets and rugs, which they carry out more as a hobby than a regular occupation. On the whole, 69.4% of the population of the four villages surrounding the KS depend on agriculture for their livelihoods. Of the household income, 63.55% and 13.66% is spent on food and clothing, respectively; 0.09% and 0.34% is spent on rent and transportation.

Beekeeping was introduced by the KS in 1993 and is becoming a thriving business in the GBP. In 1997, 700 beehives produced 6 metric tons of honey during a 45-day period in June and July; and, the average honey yield of twenty beehives kept at the station was 14.5 kg per beehive for a four-month period (March–June). The reported honey production for 2006 was 35 tons. According to an expert, we have not yet reached the potential yield. We are in the process of obtaining an ecolabel; this will increase the monetary value of the GBP honey.

4. Practices implemented for soil and water conservation

Below is a reduced facsimile of a cuneiform inscription carved by order of Darius the Great on the south retaining wall of Persepolis about 500 B.C. and may be translated into English as:



"God protect this country from foe, drought and falsehood."

The presence of numerous farming communities in the very dry areas of the I.R. of Iran is irrefutable proof that humans can live a fruitful life under extremely harsh conditions. Drylands, by definition, receive a relatively insignificant amount of precipitation. Moreover, distribution of the small amount available is erratic. What is called the mean annual precipitation (MAP) might occur only at very few events. Furthermore, drylands usually experience irregular droughts, sometimes for a few years in succession. It is mostly during such periods that improper land-use, which can culminate in desertification, takes place.

The occurrence of torrential rains in arid and semi arid zones is a rule rather than an exception. These events happen even during the most severe droughts. This is the main reason that the sedentary population in deserts had to develop ingenious techniques to harness torrents and utilize water for growing food, feed, fuel, and fibre crops. The existence of a rather direct relationship between the amount of precipitation and elevation encouraged the establishment of settlements in the mountainous regions. As the grass is more abundant and greener at higher elevations both pastoralists and mixed farmers chose mountain valleys and foothills for grazing and dry farming. As the steep slopes necessitated construction of narrow terraces requiring strong stone walls, and cultivation was much easier on sites having milder gradients, larger basins were constructed on debris cones and on the upper and middle reaches of coarse alluvial fans. Persians had learned that they could easily harness flows, divert them into small basins, and grow crops in both flat and sloping terrains.

Runoff farming, which was probably the forerunner of the qanat technology, was most certainly learned from nature. Seepage of water downstream of the runoff farms lead to the serendipitous discovery of groundwater flow and the development of the very sophisticated qanat technology. Thus, the emergence of contact springs, where the vadose zone texture was coarser than the underlying strata, was an inevitable outcome of over-irrigation of such farms. This perhaps encouraged the ancient Persians to mildly dig sloping tunnels that drained the alluvial strata. The presence of seemingly prehistoric flood-irrigated farms on the recharge area of many of the qanats in the northeastern province of Khorasan lends support to the contention that our ancestors replenished their aquifers, albeit unknowingly (Kowsar, 1991); the qanats supplied the lower lying farm fields and agrarian communities. This invention turned our country into the "land of droughts, floods, and qanats."

A variation on the same theme was floodwater irrigation of very large basins in vast floodplains on extremely low slopes. These plains had been formed by millions of years of erosion of flysch, lahar, siltstone and marl outcrops of mostly tertiary age. As these fine materials were not conducive to the formation of productive aquifers, the Persians used them for growing small food grains particularly wheat and barley. They certainly were, and still are, strong believers in the so-called *Genesis Strategy*: produce in fat years, economize in lean years.

As self-sufficiency in food became a tenet of the I.R. of Iran in its formative years, detailed examination of the runoff farming systems were performed to find the most appropriate methods for application on the large scale. We were facing serious problems; most of our qanats had dried up due to the application of an inappropriate technology, i.e. the overexploitation of groundwater through deep wells.

More than 58% of our irrigation water is supplied through underground resources. Therefore, the ARG was strongly advocated in planning and implementing the floodwater spreading (FWS) schemes. This was the main reason that we integrated the traditional knowledge with modern technology and coined the term *Abkhandari* (aquifer management in Persian), to signify the importance of all activities that result in the development of groundwater and the optimization of its use (Kowsar, 1998). The most widespread design used in present-day Iran is based on the pioneering works of three Australians: Phillips (1957), Newman (1963), and Quilty (1972). In this system, floodwater is spread as a thin sheet from level-silled channels constructed at certain intervals. The overland flow in FWS events (theoretically) does not acquire erosive velocities. We have modified the Australian design to suit our intended purposes, the ephemeral flow regimes and the lay of the land, the texture of soils, and the machinery available for construction. It should be emphasized that we are still performing research on different aspects of FWS and ARG. Our principal objective in performing such methodological activities is to elevate these ancient arts into the level of science.

4.1 Floodwater harvesting concepts

1. While the mean annual rainfall in drylands is very low, its variability is extremely high (erratic in distribution and frequency). Thus, the chance of receiving the desired rainfall at the expected time is indeed meagre. Therefore, water is the most precious commodity and flood is the largest form of supply in the drylands. Although floodwater is a renewable capital, its use must be optimized.
2. Available water capacity (AWC) is the most important direct driver of ecological sustainability in the drylands. Soil *texture* and *depth* are the two major determinants of AWC.
3. As erosion has become a byword for lower productivity due to nutrient depletion as well as reduced soil water retention, harvesting turbid floodwater on eroded land is a soil and water conservation activity. Therefore, water, an erosion agent, may become a land renovator and soil builder by transporting to and depositing nutritious sediment on the slightly-sloping, drastically disturbed lands, thus improving their texture and increasing their depth; *therefore, enhancing their AWC*. This improves their fertility and overall productivity as well. This process also modifies the topography, stabilizes the moving sands and deprives the wind of the erodible material at its source.
4. The high evaporation rate from surface waters, rapid siltation, inundation of productive lands and dwellings, forced migration of the inhabitants of the inundated area and construction sites, threats to biodiversity, reservoir leakage, earthquakes and other related environmental hazards, as well as the very high costs and relatively long time needed for their construction, make large dams the most *inappropriate technology* in drylands. Furthermore, such schemes do not benefit inhabitants of the runoff-producing headwater catchments. They not only lose most of the water that nature bestows on them, but they also lose surface soil – the life-giving substance that nothing can replace; therefore,
5. Turbid floodwater should be harnessed to build soil; restore, maintain, and enhance ecological harmony; produce virtual water through spate irrigation; and when practicable, should be stored in aquifers by employing the ARG methods and used commensurate with needs. These shall also mitigate flooding hazards.

The ARG systems, farm fields, wells and pumping stations, roads, windbreaks, fire lines, service reservoirs/fish ponds and protective structures are the infrastructures that must be in place *before* our *Aquitopia* project becomes operative. To the credit of the AM activities

Figure 2. This level-silled channel, and about 15 km like it, protects the *Aquitopia* from flooding, while artificially recharging an aquifer and irrigating a pasture (Gholamreza Ghahari).

and the greed of land speculators, about 500 ha of choice land on the site appropriated for the project had been illegally brought under the plough to establish ownership. This delayed our construction activities by about three years. In the meantime, we constructed 160 ha of the ARG systems upstream of the project site in order to protect it against destructive floods that originate from the mountains downstream of our main diversion structure. The main conveyance canal route has been surveyed, two small earth dams that form the main sedimentation basins have been designed, and the fund for their construction is being appropriated. Of a 3.7 km conveyor-spreader channel with a design capacity of $25 m^3 s^{-1}$, 2.8 km has been completed. We have also constructed 70 ha of the ARG systems on the project site. Moreover, eight masonry chutes, using 80 m^3 of rocks and concrete have been constructed at strategic points assuring the safety of the ARG systems.

Other scientific activities carried out during the project phase are described below:

1. **The effect of floodwater spreading on the field soil water balance in the Gareh Bygone Plain, I.R. Iran**. This study formed the MSc thesis of Mr. Peter Corens of Katholieke Universiteit Leuven, Belgium, for which Prof. Dirk Raes was the promoter and Prof. Ahang Kowsar was the co-promoter.
   Prof. Raes is using the data from this study to fine tune the BUDGET model to estimate soil water balance, and to find what percentage of the diverted floodwater reaches the watertable under different MAP. Mr. Corens was with the KS from 3 September to 31 October 2004.
2. **Water and sediment harvesting in the Gareh Bygone Plain, I.R. Iran.** This study forms the Ph. D. thesis of Mr. Nosratollah Esmaeili Vardajani of Universiteit Gent, Belgium, for which Prof. Donald Gabriels is the promoter and Prof. Ahang Kowsar the co-promoter. Mr. Esmaeili measured the depth of the freshly deposited sediment at 162 nodes and 154 extra points upstream of the earth banks in an ARG system which had been under operation since 1983. He also determined infiltration rate and saturated hydraulic conductivity at 30 of the same nodes and 11 points on the watershed whose discharge is used for the ARG. He further collected samples of sediment and the underlying soil at the very same 30 nodes and 11 points. Particle size distribution and organic matter content of these samples were determined at our laboratory. These data are being analysed at Ghent University and used to write the thesis. Mr. Esmaeili was with the KS from 1 February to 6 May 2004. It is hoped that the practical implication of these two studies will help towards a better design and operation of the ARG systems.
3. **Transport of nitrate and its fate in an unconfined sandy aquifer of Gareh Bygone Plain, I.R. Iran**. This study formed the Ph. D. thesis of Mr. Mehrdad Mohammadnia of Universiti Putra, Malaysia. The presence of geologic nitrogen in the AJF, which covers the Bisheh Zard Basin that supplies floodwater to the ARG systems, is a cause for concern. Mr. Mohammadnia discovered that although nitrate concentration in the recharge water is relatively high by US-EPA (Environment Protection Agency) standards, the groundwater is safe for drinking. Apparently, *Eucalyptus camaldulensis* Dehnh. fillers nitrate from groundwater; calcium carbonate, which is abundant in our soils, may also function as a remediator.
4. **Nitrogen fixation by *Panicum antidotale* Retz**. This pioneer species is a drought-tolerant C_4 grass that performed exceedingly well in the moving sand dunes of Khusistan in southwest I.R. Iran. We had speculated that its green color, in pure sand devoid of nitrogen, may be due to its N-fixation ability. The preliminary results have encouraged us to further

Figure 3. Mean annual carbon sequestration of these Eucalyptus camaldulensis Dehnh. trees (planted at 3 x 3 m spacing) at the age of 18 has been 2.27 tons ha^{-1}. At $4.25 t^{-1} of CO_2 (Chicago climate exchange, Dec. 2006), this amounts to $ 31.69 ha^{-1}. This carbon rent is potential seed money for desertification control activities. Bioremediation capacity of this species for nitrate and ammonium was determined in a Ph.D. dissertation project in the Gareh Bygone Plain. Floodwater-carried geologic nitrogen is a boon to vegetation in such organic matter deficient sandy desert, but a bane to human well-being. The conveyor- spreader channel, which slopes from right to left, discharges a thin sheet of floodwater to the foreground pasture. Water, forage, and shade for the livestock bring exuberance to the herders (Sayyed Ahang Kowsar, Mehrdad Mohammadnia).

our studies, particularly for the identification of the N-fixing micro-organisms that inhibit its roots. We intend to use this grass for erecting hedges on mild sloping sedimentation basins to hydraulically level the land, and prepare it for surface irrigation.

5. **An investigation of carbon sequestration by standing crop of dominant shrub species and soil in the Gareh Bygone Plain**. This study formed the MSc thesis of Mr. Rahim Froozeh of the Gorgan University of Agriculture and Natural Resources Sciences, Iran. Mr. Froozeh discovered that the aboveground carbon sequestration by *Helianthemum lippii* (L.) Pers., *Dendrostellera lessertii* (Wikstr.), and *Artemisia sieberi* Besser was 100.09 and 50.63 kg ha^{-1} in the floodwater-irrigated and control plots, respectively. The soil carbon content in the same treatments was 7.02 and 2.63 kg ha^{-1} in the upper 30 cm, respectively. A paper based on this study has been accepted for publication by the Scientific and Research Quarterly of Agricultural Jahad.

The UNESCO-Tehran Cluster Office is gratefully acknowledged for partially supporting these five studies.

6. **Soil microbiology**. Soil biological activities are a useful indicator of its quality. Provision of water and substrate supply, mostly carbon, has resulted in a substantial rise in the number of nitrobacteria in the spreaders. The total population of soil micro-organisms in the spreaders increased respectively by 34 and 24 fold at the sites planted with *Eucalyptus camaldulensis* Dehnh. and covered with native pasture as compared with the control. It is noteworthy to report that these ratios became 6 and 4 when compared with the population of soil micro-organisms in the irrigated fields on the same soil in the GBP. A paper based on this study has been accepted for publication by the *Iranian Journal of Soil and Water Sciences* (Rahbar et al., 2006).
7. **The Carbon sequestration potential of *Eucalyptus camaldulensis* Dehnh. and *Acacia salicina* Lindl. plantation in Fars province, I.R.Iran**. This study formed the Ph. D. dissertation of Mr Sayyed Kazem Bordbar of Islamic Azad University, Science and Research Branch. It is a fact that the carbon dioxide concentration in the atmosphere has increased significantly after the Industrial Revolution in the eighteenth and nineteenth centuries in Europe and the U.S. The fast-growing trees that are not burned are among the best agents of C-sequestration. As the establishment of windbreaks and shelterbelts is accepted as a desertification control measure, afforestation with adapted eucalyptus and acacia species offers a successful method of C-sequestration. Mr. Bordbar has discovered that the above-

ground carbon sequestration potential of an 18-year old, spate-irrigated *Eucalyptus camaldulensis* Dehnh. was 3.619 tons $ha^{-1}yr^{-1}$ for the more productive sites, and 2.273 tons $ha^{-1}yr^{-1}$ for the less productive sites. For *Acacia salicina* Lindl. this was 1.502 tons ha^{-1} yr^{-1} in sites with low productivity. Should the industrialized countries wish to pay us "carbon rent", we will be happy to filter the obnoxious gas from the Earth's atmosphere.

The UNU is gratefully acknowledged for partially supporting these two studies.

8. **Biodiversity monitoring**. Drastic environmental changes brought about by floodwater spreading have shown different effects on various range plant species. Although most plants in arid lands react positively to the additional water and deeper soils provided for them, some react differently. Some plants do not tolerate inundation or burial by sediment. Therefore, new species might occupy the 'improved' surroundings and eliminate some of the endemic plants to date. Even though we have been monitoring such trends for the past 15 years, as the ARG systems are grazed by livestock and wildlife, we are not absolutely certain of the intensity of change.

Figure 4. One of the 14, 5 x 2 m plots established for monitoring biodiversity. These long-term plant and soil experiments are keys to managing drylands' rapidly changing ecosystems (Sayyed Hamid Mesbah).

The establishment of 12.5 x 2 m plots in the BZ1ARG system (Bisheh Zard 1), and 2.5 x 2 m plots outside of the system as control, and the semi-annual monitoring of their plants and soil will clear some of the unknowns about the vegetative cover reactions to floodwater spreading. Moreover, the controls are the baseline through which some of the changes that are going to happen to this ecosystem may be evaluated.

The following species were recorded in the plots on 9 May 2007:

1- *Artemisia sieberi*
2- *Centaurea virgata*
3- *Heliantaemun lippii*
4- *Convolvulus virgatus*
5- *Carex stenophylla*
6- *Medicago radiata*
7- *Medicago laciniata*
8- *Medicago rigidula*
9- *Acantholimon sp*
10- *Stipagro-tis plumosa*
11- *Bromus danthoniae*
12- *Stipa capensis*
13- *Phalaris minor*
14- *Poa sinaica*
15- *Aegilops kotschyi*
16- *Dendrostellera lesserti*

9. **Jojoba plantation**. *Simmondsia chinensis* (Link) Schneider, commonly known as jojoba, is a dioecious evergreen shrub native to dry regions of southwestern USA and northern Mexico. This species is very tolerant of drought and heat, and is of great importance with regard to desertification control. Moreover, it produces seeds that contain about 50% liquid wax, a unique substance, which is of great value in cosmetics, food, pharmaceuticals and in other industries; as such it will generate income for the local population. This study is conducted

to investigate the adaptation and performance of jojoba under rainfed and floodwater-irrigated conditions in the GBP. The treatments are control (rainfed), floodwater irrigation, and floodwater irrigation plus irrigation once every twenty days for one year after planting. To help their establishment, all seedlings, irrespective of treatments, will be irrigated every fifteen days in the dry season of the first year of planting. Growth, mortality and phenological factors including flowering, sex differentiation etc. of the plants will be monitored on several occasions each year. Final analysis and assessments will be made after four years.

In late February 2007, the potted two year old jojoba seedlings, which had been raised at the Sarab-Bahram Nursery (150 km to the west of Shiraz), were transported to the GBP (the seed origin was a raised stand of mature jojoba trees in Jahrom, 50 km to the southwest of GBP). The average height of the seedlings before planting was 24 cm. Two adjacent experimental plots, one on a high ground as the rainfed treatment and another on a low one, which will be floodwater-irrigated, were ripped by a bulldozer on the contours to a depth of 50 cm in early March 2007. Then a total of 425 seedlings were planted at 2 x 3 m spacing in a randomized statistical design. All seedlings were irrigated after planting. On 14 May 2007, the site was visited and the necessary assessments were made. All seedlings were found under suitable conditions and were growing well, producing new stems and leaves. Only twelve seedlings seemed to have turned yellow and pale or were dead, and five seedlings were probably uprooted in early April by unknown people. The lost seedlings will be replaced in the coming autumn or late winter when climatic conditions are favorable. Sex differentiation was observed in three seedlings, two of which were male and one was female. The plots will be fenced with barbed wire by mid/late summer before the permitted grazing season at the KS. The growth assessments will be carried out after the growing season in mid-autumn.

The SUMAMAD Programme is gratefully acknowledged for partially supporting these two studies.

5. Income-generating activities to diversify the economic base at household levels

Note: As we have been implementing the SUMAMAD philosophy since 1983, about nineteen years before its inception, we are certain that the locals appreciate continuation, and especially any improvement in our activities.

The constant dispute between the research team and the land speculators on the one hand, and among the land speculators themselves on the other, together with a lengthy drought, prevented the inhabitants of the three villages, who share the aquifer recharged through our

Figure 5. The drought enduring jojoba (*Simmondsia chinensis* (Link) Schneider) may prove to be a good candidate for afforestation of some marginal drylands. Water shortage may force us to replace *Eucalyptus camaldulensis* Dehnh. trees with this shrub. We planted these seedlings in March 2007 (Sayyed Morteza Mortazavi).

SUMAMAD-related activities, to benefit from our floodwater harvesting activities. During the 2005–06 period, the sum of USD 6,758.62 was spent on buying rocks and graded gravel from the locals, and paying wages to masons and laborers who constructed the chutes in the ARG systems.

Honey production at the KS provided seasonal employment for many hand laborers. The honey yield for 2006 was reported at 35 tons at the KS. An offshoot of this business is the new bee colonies that inhabit the watershed. The honey from such natural beehives is sold as 'mountain honey', which is twice as expensive as the customarily produced type. We have no idea of the amount collected.

Double kidding is an annual bonus that most herders obtain from abundant forage available on the spreaders in the autumn, when there is a shortage of feed in the surrounding rangeland.

As our previous studies have shown, each 4 ha of an ARG system provides one employment opportunity; therefore, we expect to provide 125 jobs when we finish constructing the 500 ha in the planned *Aquitopia*. A strong majority, mostly medium and low-income farmers and herders, are happy with our presence and eagerly anticipate future prospects. However, a few petty chieftains, the remnant of the old nomadic systems, are concerned about their eroding authorities.

6. Results obtained

During five flood events (30 March 2006, 5 September 2006, 17 December 2006, 4 February 2007, 29 March 2007) we estimated the flow, measured the flooding duration, and calculated the flood volume for each event; we harvested approximately 190,700 m^3 of floodwater in three ARG systems totalling 160 ha (most of it in

RECOMMENDATIONS FOR POLICY-MAKERS

It is water-not oil- that sustains life in deserts!

I.R. Iran is the land of drought, flood and groundwater. On average, we annually waste about 50 km^3 of floodwater, while overexploiting our groundwater to the tune of 6–7 km^3.

Our most precious asset in this land is the 42 million ha of coarse-grained alluvium with a potential capacity of more than 4,200 km^3. If filled with floodwater, it can ensure us against 40 years of severe drought.

We are losing our precious arable land to erosion. Floodwater harvesting is the most logical method of soil building and restoring the drastically disturbed lands.

Floodwater irrigation of our rainfed and traditionally irrigated farms in plains not only saves a tremendous volume of surface and groundwater, but also helps the artificial recharge of groundwater where the farm fields are underlain with potential aquifers.

Desertification control though floodwater harvesting is the most economical method of carbon sequestration and combating climate change. It further creates livelihoods for many desert-dwellers.

Aquifer management in water scarce farming communities facing cityward migration and in deserted villages is the most appropriate and economical technology for creating employment opportunities. At the current exchange rate, it takes USD 6,000 to create one job to support a family of five.

Floodwater harvesting is the easiest and most economical way of flooding mitigation, decreasing damages to infrastructure and reducing casualties.

Involving nomads and farmers in action research is a good way to teach them about stewardship of natural resources, particularly the optimization of soil and water use. And the most important of all, **policy-makers in drylands should be ecologists *par excellence*, or heed their advice. They should base their development aspiration and programs on the sustainable management of their country's natural resources**.

a 27 ha system which had been functioning in the first two events). As about 80% of the water has recharged the aquifer, this has been effective in producing about 127 tons of wheat grain and 148 tons of straw, bringing in about USD 35,534, about one half of which is the net profit. This revenue is enough to support fifty people for a full year.

A very important outcome of more than three years of legal and social wrangling has been the establishment of two cooperatives for the potential members of the *Aquitopia*. This is essential in acquiring the substantial funds needed to implement the project. We are pushing to form two more cooperatives in order to engage about 2,500 people to sustainably manage a 6,000 ha sandy desert that overlies two aquifers with a total capacity of over 200 million cubic meters of freshwater.

7. Recommendations for sustainable dryland management

Water is an incredibly valuable commodity in drylands, and is therefore the topmost limiting factor for the sustainable management of such ecosystems. Water insecurity represents a powerful risk factor for poverty and vulnerability. This becomes doubly important where the inhabitants solely depend on a water-based economy for their livelihoods. Furthermore, arable soils occupy a position almost on par with water in such lands. Therefore, wise management of these two resources, irrefutable in drylands, takes precedence over other policies in running a country.

According to FAO (1993), the worldwide area of arable land was 1,442 mha in 1990. Conversion to non-agricultural uses, erosion, salinization, inundation and toxification (different aspects of land degradation) takes about 14 mha of these lands out of production every year. Thus, assuming a zero population growth and keeping all production parameters constant, humans will have to make do without most of the actual agricultural lands by 2090. This prediction leaves us no choice but to conserve the soils we presently farm and to reclaim the drastically disturbed lands in order for our progeny to retain the right to live on the planet. Floodwater spreading, particularly for the ARG, and an intelligent use of land and water resources in terms of AM, potentially offer a panacea for solving this nexus. As water is a renewable resource, and drought is an ever present threat to our land, recharging the depleted aquifers offers the best solution to attain water security.

Iran is endowed with 42 mha of land covered with coarse-grained alluvium of good quality, ranging in depth from 10 to 1000 m, and in coefficient of yield from 2–35%. Taking the mean depth and coefficient of yield at 100 m and 10%, respectively, we may store 4,200 km^3 of water underground, equivalent of 10 times our country's MAP. Furthermore, assuming zero population growth and water consumption equal to that of 2006, we can go through a 40-year drought without being deprived if we fill up this subterranean reservoir.

Rejection of the frequently held misconception about water scarcity in deserts is the first step that 'decision-makers' can take. Aridity was the main excuse used by the defunct monarchy for the pseudo-industrialization of Iran.

Floodwater may function as the most logical renovator of eroded land when the dissolved and suspended materials are nutrients, harmless soil particles and organic matter (turbidity). Flooding casualties and damages are enormous in the I.R. of Iran. Floodwater harvesting is the most logical way to transform a problem into a solution. Therefore, FWS restores, maintains, and enhances the ecological harmony of the landscape. Thus, the nemesis of water resource engineers transfigures into the guardian angel of aquifer managers.

The *Land of Iran* has one of the highest erosion rates in the world. Overgrazing, excessive deforestation, application of inappropriate technologies, and conversion of sloping rangelands to farm fields have created acute environmental problems. Implementation of the AM concept on the largest possible extent is strongly recommended. Floodwater irrigation of rainfed and irrigated farms increases yield and recharges groundwater in the first case, and saves some irrigation water in the second. Herbage production in rotation with small-grained cereals helps the ecological restoration of depleted rangelands. Carbon sequestration in roots of all plant materials and the aboveground parts of trees used as windbreaks and shelterbelts is an added advantage of the application of the AM technology.

The unemployment rate in I.R. Iran currently stands at 11.3 %, which translates into a potential 3.5 million workforce. As 4 ha of FWS for the ARG provides one employment opportunity at lowest cost, the sustainable management of marginal drylands, through the direct application of the AM technology in 14 mha, provides direct employment opportunity for 3.5 million people, and livelihoods for at least 12 million people; desertification control in its true sense. Although we have not surveyed the number of people who would benefit from the value-added businessess outside the farm, a large number of agri-busines firms will be potential beneficiaries of the 14 mha farm fields. It is imperative to realize that most of the unemployed are the nomads and farmers who have migrated to cities in search of better livelihoods. As they do not have to pay for land and housing if they stay, AM provides the most economical means of employment creation.

7.1 Economic evaluation

Very valid and important questions asked about the AM activity concerns its economics. Economic viability is what financiers and budget bureaus are mostly concerned with. Detailed items of implementing AM activities on a large scale (at least 100 ha) per ha are as follows:

Surveying: 30 minutes
Bulldozer: (125–160 HP) 3 hours
Masonry: 1 cubic meter
Gabion (apron, diversion weir): 0.2 cubic meters
Planting trees: 0.2 man/day i.e. one man can plant 5ha per day.

At the current exchange rate, the costs per ha add up to USD120.00. The benefit (B): cost ratio (C) at the KS, without considering environmental benefits, is 20. Should one include rather intangible items (such as warmer climate in winter and cooler in summer: cleaner air, no dust; a verdant scenery; providing a refugee for wildlife, etc), again without considering human fatalities during flooding, the B:C ratio amounts to 90. Therefore, as one does not have to buy land (irrigators have abandoned their farm fields due to the lack of water), an investment of USD6,000 for the water supply (including the ARG system, wells and pumping stations) and laser-assisted land leveling in the present day I.R. Iran creates an employment opportunity. It is envisioned that about 3% of the value of the capital stock should be spent annually on the replacement and maintenance of the irrigation infrastructure.

Policy-makers in the drylands should be ecologists *par excellence* or genuinely seek their advice. Unfortunately, this has not been the case. Environment in general and deserts in particular have a very delicate balance that could be irreversibly tipped in favour of destruction if upset by humans. Although desertification is prevalent in drylands, it also occurs in humid areas. A case in point is Iceland where deforestation and imprudent grazing have degraded a considerable expanse of the country, which has the highest per capita water resources in the world.

An ecologist policy-maker bases his/her ambitions for development on the sustainability of the available resources taking into account extreme climatic phenomena such as prolonged droughts and unusual flooding. Sustainability in resource use dictates that production systems should be managed so diligently that the same, if not richer assets, are left for future generations; because future flows of water are more or less fixed, over-consumption leads to asset depletion and unsustainable hydrological debt.

If we take for granted that reduced groundwater discharge is a variation of drought (Kassas, 1987), then the falling water table may be perceived as a very important agent of desertification in arid areas where most water needs are supplied through underground resources. Therefore, we have been living with a continuous drought since 1945, when cable tool, and later, rotary drilling machines and powerful pumps arrived in Iran. Moreover, water and electricity subsidies have created incentives for the inappropriate cropping pattern and the overexploitation of groundwater; the most absurd idea has to be attributed to wheat exportation.

The ill-conceived water policies up till now in I.R. Iran shall prove ruinous if projected wheat exports happen. The most realistic minimum water use efficiency (dry matter or harvested portion of crop produced per unit of water) for wheat grain is 1 kg per m^3. As our irrigation efficiency is at most 40%, at least 2.5 m^3 of water is used to produce 1kg of wheat grain. Assuming that the minimum per capita daily domestic water requirement is 20 litres, 3 kg of wheat produced for export will consume the entire annual domestic water requirements of one person! Saudi Arabia prided itself in the 1980s with wheat export; farmers were paid USD 1.00 per kg, while the market price was about USD 120 per metric tonne!

Short-sightedness, poverty, ignorance and greed have wreaked havoc on the environment, particularly in deserts. Water management is the best policy for desertification control. The predictability of water supply and the sustainability of water-based ecosystems are crucial dimensions to water security. Irrigation offers a way to reduce the risk and vulnerability associated with unreliable or inadequate rainfall. The groundwater problem now presents a risk to food production in large swathes of the developing world, with attendant risk for rural livelihoods. This stresses the need for constant vigilance in water demand and supply management.

Applied research is a bulwark against ignorance. The establishment of accessible research plots in water-scarce areas is the first step in showing the irrigators and herders how to harvest floodwater, particularly in the case of ARG, and how to optimize the resources in harsh environments. This calls for the training of a strong group of research scientists and extension agents who live on the sites and participate in active research. Scientific articles, reported in the most prestigious journals, do not carry weight with those who have to eke out a living from the fast dwindling natural resources. They believe that if they do not plunder the resources, somebody else will. Making them co-operators in learning, and partners in crop harvesting and livestock production on the research plots seems to be an easy way to reach and transform them into extension agents who can communicate with those in need of consultation. Moreover, this minimizes the distrust between the public servants (stewards of the natural resources) and the beneficiaries while maximizing the benefits accrued from shared solutions.

A very important research topic concerns the fair distribution of water in terms of floodwater diversion from ephemeral rivers, or the flood pulse from the permanent ones. The dilemma facing the floodwater harvesters is to know how much water should be allocated to maintain the integrity of the environment; economy should not take precedence over ecology in this regard.

The next step is to authorize local partners to implement what they have learned under the supervision of benevolent executives such as policy-makers and administrators. Where farmers have more authority and responsibility over water management, transparency can improve pricing, cost-recovery and performance. In this regard, installation of a water meter on each pump is an absolute necessity. *The irrigators should have to be charged exponentially for water withdrawal above the volume designed for them.*

The sustainable management of marginal drylands philosophy so far has not considered global warming. Policy-makers in drylands are so occupied by their day-to-day problems that they consider this threat as non-existent. Few warnings have been more perilously ignored than those involving climate change. As this phenomenon increases the challenge of sustainable development in deserts, it should be taken very seriously if the dryland inhabitants are concerned for the well-being of future generations. Therefore, assuming that this phenomenon will increase the incidence of droughts and floods, the AM concept shall play an important if not vital role in water resources strategies.

8. National seminars

1. The first national sustainable management of marginal drylands workshop, was held on 25–26 December 2004 and was attented by thirty participants.

The presence of Prof. Taqi Shamekhi, College of Natural Resources, University of Tehran, who is a highly influential advisor to the Ministry of Jihad-e-Agriculture, and a fortunate and timely flood event during the workshop were instrumental in the development of a national policy on aquifer management. Prof. Taqi Shamekhi, who has been familiar with our work since 1979, experienced floodwater spreading for the first time. In keeping with the well-known adage, "seeing is believing", he has now become a staunch supporter of AM. He has been instrumental in convincing the government to implement our concept on 1.5 million ha during the 2006–2010 period. An important point in Prof. Shamekhi's presentation was the issue of 'rights of ownership' of individual villages i.e. the borderline between public and private land. This has to be settled in advance of the development projects' implementation.

Two graduate students from Shiraz University had carried out their master's theses at the KS under the supervision of Prof. Abdolmajid Sameni, his presence was therefore fruitful for the future cooperation between the university and the KS. Moreover, Mr. Mohammad Reza Haeri, a city planning architect, who actively participated in debates, has agreed to help in the design of a green village (*Aquitopia*). The participants were impressed by the scientific quality of the projects implemented at the KS.

2. The second national sustainable management of marginal drylands workshop was held on 30 November–1 December 2005 and was attented by eighty-six participants.

We had a larger and more influential group of participants compared with the first workshop. Dr. Abdin Salih, Director of UNESCO-Tehran Cluster Office; Prof. Najaf Ali Karimian (soil chemistry) and Prof. Ali Akbar Sarafraz (statistics) of the Shiraz University; Ms. Laleh Daraie, National Coordinator, UNDP-GEF/SGP; Mr. Nowzar Emami, Governor of Fasa; Dr.Mohammad Hussein Assareh, Director, Research Institute of Forests and Rangelands; Dr. Ziaeddin Shoaei, Director, Soil Conservation and Watershed Management Research Centre; Mr. Abdol Karim Razavi, Director, Ministry of Jihad-e-Agriculture, Fars Province Organization; Dr. Yousef Ali Saadat, Director, Fars Centre; as well as many of provincial and local authorities, researchers, technicians and representatives of villages concerned by the SUMAMAD activities made this workshop a successful event. The presence of the above-named influential authorities at the site helped in convincing the researchers, and national and local authorities of the importance of the aquifer management activities.

The UNDP-GEF/SGP National Coordinator agreed to co-finance our *Aquitopia* project to the sum of USD75,000 if we establish cooperatives in the three villages benefiting from the project.

On the scientific side, Prof. Sarafraz constructively criticized the reported studies as regards their sampling validity. The ensuing discussion and sometimes heated debates, added to the liveliness of the workshop. Prof. Karimian discussed the analytical methods suitable for our calcareous soils, some of which where developed by himself. Mr. Hans-Paul Velema, a trainee from Wageningen University, Holland, whose presentation regarding the role of quail bush in hosting the curly top virus – which is transferred to sugar beets by a vector, a certain species of cicadae – put our worries regarding the sugar industry in the GBP to rest.

A very significant incident at this meeting involved the presence of five women from the surrounding villages. This was the first and only time in the 24 years of our presence here that women were allowed to attend our meeting and be given an opportunity to speak.

3. The third national sustainable management of marginal drylands workshop was held on 13–14 September 2006 and was attented by seventy-two participants.

The presence of Prof. Keramatollah Izadpanah, a renowned Iranian plant virologist; Dr. Dogani, the Fasa District Representative to our House of Representatives; Mr. Zarea Poor, Governor of Fasa; Dr. Sharifi, Head, Watershed Management Division, the Ministry of Jihad-e-Agriculture; His Honor Tahmasebi, the Fasa District Deputy Judge; and a few local, provincial and national authorities awarded credibility to our claim to the land given to us by the government of the I.R. Iran for the sole purpose of establishing the *Aquitopia*. Furthermore, attendance of many research scientists, progressive farmers of neighboring districts, and local farmers and herdsmen made this gathering highly informative and noteworthy.

The main outcomes of the workshops in a nutshell

The Province of Fars holds the national record for the production of the majority of agricultural commodities, both on a hectare and total yield basis. This has come about through many essential factors, the most limiting of which is water shortage. About 80% of the irrigation water in this province is supplied through the over-exploitation of groundwater resources. Of the total of 63 monitored aquifers in our agricultural district, 61 show negative trends. The annual shortfall of water in this province is estimated at 2 billion m^3, which is equal to one-third of the country as a whole. Some doomsayers have correctly predicted that we will be out of groundwater in 8–10 years at the current pumping rate. The SUMAMAD workshops have provided a forum to discuss the pros and cons of our current water policies. Our serendipitous selection of the GBP for the site of desertification control through the aquifer management studies have convinced many farmers that their future well-being rests with ARG for the sustainable management of their land, which is mostly marginal. I strongly believe that the seven year drought made the policy-makers take a closer look at our SUMAMAD supported activities. Solid evidence of this is the appropriation of USD 1 billion for the management of aquifers and watersheds in June 2006. Of this fund, about USD 215,000 will be given to our *Aquitopia* project and USD 107,500 to an ARG project in Sarvestan (100 km SE

Shiraz), whose farmers' representatives attended the third workshop.

Finalizing the establishment of two cooperatives, and pushing for the formation of two more as potential members of *Aquitopia* is another outcome of the SUMAMAD workshops. Moreover, local authorities are actively in finalizing the paperwork.

I strongly believe that exposure through the SUMAMAD project, and the publicity generated by the workshops, has been influential in convincing some sceptics of the viability of the aquifer management concept.

9. Research institution and team composition

9.1 Research institution

Fars Research Centre for Agriculture and Natural Resources is a satellite of Agricultural Research and Education Organization, which is headed by the Vice Minister of Jihad-e-Agriculture for Education and Research.

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9.2 Team composition

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Ecology: Behrooz Malekpour (PhD).
Agro-nomy: Eqbal Hadaeq (BSc).
Pastoralism: Gholamabbas Ghanbarian (PhD candidate). Sayyed Hamid Habibian (PhD); Bahman Ilami (BSc). Abdolhamid Karimi (MSc); Sayyed Hamid Mesbah (PhD candidate).
Forestry/Horticulture: Sayyed Kazem Bordbar (PhD). Masoud Fayyazi (MSc); Sayyed Morteza Mortazavi (PhD). Yousof Ali Saadat (PhD).
Economy/Sociology: Gholamreza Bazhian (PhD); Sayyed Mohammad Hashem Mousavi Haghighi (PhD candidate); Javad Zabetian (MS).

Technicians

Hosein Arayesh Kashkooli; Kohzad Arjomandi; Noorollah Arjomandi; Nazar Ali Fereidouni; Gholam Nekouian.

10. Publications as a result of SUMAMAD

One paper based on carbon sequestration by standing crop of dominant shrub species and soil in the Gareh Bygone Plain by Mr. Froozeh *et al*.

One paper based on soil microbiology by Dr. Roosta.

One paper based on carbon sequestration by *Eucalyptus camaldulensis* Dehnh. by Dr. Bordbar *et al*. has been accepted for publication by three accredited Iranian scientific journals.

Two papers based on nitrate remediation of the same tree by Dr. Mohammadnia *et al*. are being prepared for submission to Journal of Environmental Quality.

One paper on the theoretical design of stilling basins for the artificial recharge of groundwater using large flows, connected with our *Aquitopia* activities is being prepared by Dr. Dehghani and Dr. Kowsar.

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5 Dana Biosphere Reserve

Jordan

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1. Main dryland challenges at the project site

The main dryland challenges at Dana BR site include:

- The over-exploitation of natural resources from over-grazing, wood collection, and hunting.
- The unsustainable use of the drylands: large areas of drylands that were previously unsuitable for agriculture are used now for agriculture uses.
- The lack of integration between projects and polices from most of the agencies in drylands, which results in a fragmentation of results and efforts.
- The substantial variation in annual rainfall from one year to another makes it difficult in terms of proper land planning due to the lack of good and long-term databases.
- The shift of traditional sustainable uses of drylands to modern short-term investments, which cause further deterioration of drylands and its natural resources such as the over-pumping of water that causes a further decline in the level of all the aquifers, greater soil salinity, and a greater use of chemical fertilizers resulting in more chemical residuals in soil, greater soil erosion.

2. Environmental characteristics of the study site

2.1 Climate

The climate in Dana BR and its surroundings differ from the eastern highlands, where the altitude reaches 1,600 m above sea level, to western low lands, where the altitude reaches 100 m below sea level. The climate in the highlands during winter is cold and rainy with temperatures that vary from 15°C to –10°C and rain precipitation ranges from 350 mm in good years to 100 mm in dry years.

2.2 Geology and geomorphology

The biosphere reserve (BR) is a complex of valley and mountain systems. The Dana Valley is the major feature in the reserve. The BR represents a cross-section of the main geological layers and formations in the reserve. These layers all outcrop along the valley, and starting from the lower altitudes they include: Holocene and Pleistocene (1.8 million years old) alluvial material; granite and volcanic outcrops; several layers of the lower most part of the Cambrian-Ordovician (570 million year) Rum sandstone group. In addition, many other valleys traverse the reserve such as Wadi Al Barrah, Wadi Khalid, Mahash, Ratieh and Wadi Ghwebbeh. Figure 1 shows the main geological features of the reserve.

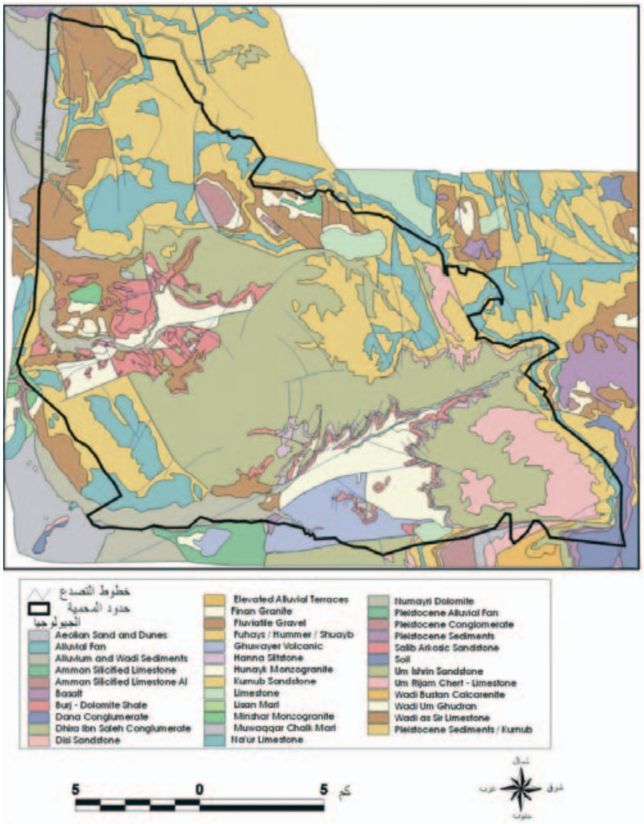

Figure 1. Geological map of the Dana Biosphere Reserve

2.3 Soil characteristics

The soil type and structure of the reserve vary from one area to another in the 300 km² of the reserve area; the reserve has seven types of soils, which are as follows:

1. GAR soil: has a sandy-sandy clay structure; the sand content of this type of soil reaches 80% with an average soil depth of 80 cm and a low content of CaCo3 (calcium carbonate). This type of soil exists at the northern and south western areas of the reserve.
2. Hay soil: is present at altitudes from 300 m to 1,500 m and consists of 35% clay and 15% sand with the remainder made up of mixed types of soils and stones. This type of soil exists at mid- and eastern parts of the reserve.
3. TAD soil: this soil has 50% of it is structure made up of sand, the soil content of stones increases with depth to reach 80% at a depth of 50 cm.
4. TAW soil: its structure is made up of 45% clay and more than 50% lime.
5. ARA soil: it consists of 35% sandy-lime structure and 35% stones and is found at the southwestern part of the reserve.
6. TIR soil: it consists of 35% clay, with the rest is lime and stones and is found in the middle of the reserve.
7. SWN soil: it consists of 45% lime, and a content of sand, lime and stones and is found in the western part of the reserve.

2.4 Biotic characteristics

Dana BR represents four of the biogeographical zones that exist in the Middle East, with different characteristics (Figure 2). These bio-geographical zones are:

1. *The Mediterranean biogeographical zone:* it covers 70 km² (23% of the reserve area), and has an altitude range from 800 m to 1500 m above sea level. This biogeographical zone is considered to have a wealth of biodiversity. It contains four vegetation types: a juniper vegetation type, an oak vegetation type, a steep non-forest vegetation type, and a water vegetation type.
2. *The Irano-Turanian biogeographical zone*: it covers 68 km² (22% of the reserve area), and has an altitude range from 400 m to 800 m above sea level. This biogeographical zone is considered to have the second richest biodiversity. It contains two vegetation types: a steep vegetation type, and a water vegetation type.
3. *The Sudanian biogeographical zone*: it covers 148 km² (48% of the reserve area), and has an altitude range from 100 m to 400 m above sea level. It contains four vegetation types: a juniper vegetation type, an oak vegetation type, a steep non-forest vegetation type, and a water vegetation type.

4. *The Saharo-Arabian bio-geographical zone*: it covers 20 km^2 (7% of the reserve area), and has an altitude range from 100 m below sea level to 100 m above sea level. It contains one vegetation type, which is the sand dune vegetation type.

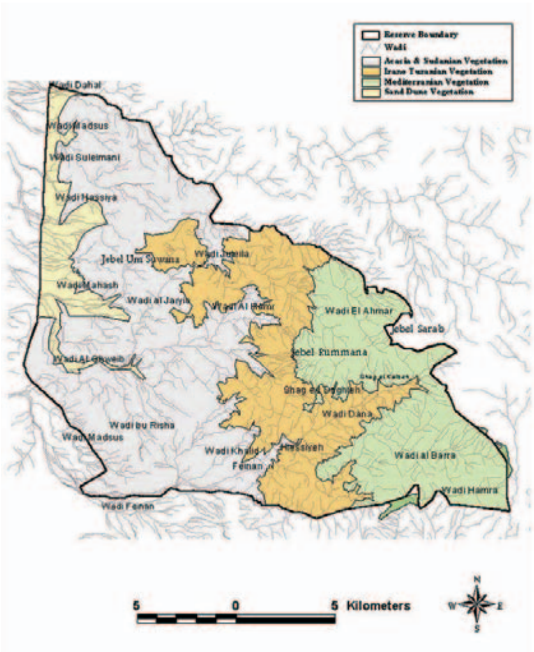

Figure 2. Biogeographical zonation map of Dana BR.

2.5 Flora

The reserve contains more than 833 species of plants, which represent one third of the plant species in Jordan of which 93 species are considered rare, and three species are considered new to science, these three species are:

1. *Silene danaensis*
2. *Micromeria danaensis*
3. *Rubia danaensis*

2.6 Fauna

There are more than 258 species of invertebrates recorded in Dana BR. There are two species of amphibians in the reserve, and 42 species of reptiles, of which one is a globally endangered species. There are 215 of birds in the reserves of which four are globally endangered species. There are 38 species of mammals recorded in the reserve.

3. Socio-economic characteristics of the study site

3.1 Social structure of the population

Dana Biosphere Reserve covers about 300 sq. km situated within Tafilah governorate. The population of villages and populated areas around the reserve is about 33,400 of which 24,900 are from Tafilah, Aqaba and Karak governorates dispersed in villages and small towns; they have direct contact with the reserve and are considered as target groups. As can be see in Table 1, the eastern highlands of the reserve, administratively speaking, is part of the Tafilah governorate with 21,200 inhabitants while the lower western part is part of Aqaba (Feynan, Rashaydeh, Qraiqrah) and Karak (Guaibeh) governorates with 3,700 inhabitants.

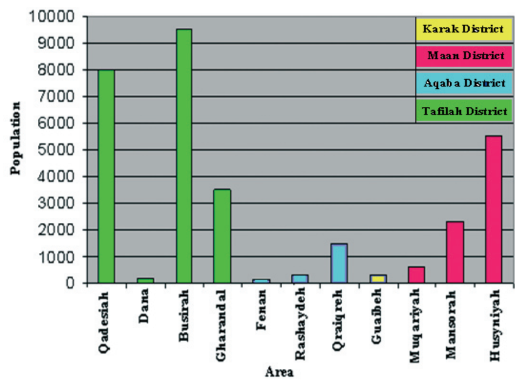

Table 1. Population distribution around the Dana Biosphere Reserve.

During the last fifty years these villages, especially those on the eastern and northern parts of the reserve, have witnessed substantial development, which has contributed to their significant lifestyle change. The local people, who were once nomadic and practiced traditional farming and grazing, have become more settled, and the villagers now live in cement houses with electricity and water, they also have easier access to infrastructure such as schools and health services.

The local people living around the reserve originate from different clans and tribes. People in the upper eastern and northern areas work as farmers, and depend mainly on government jobs as well as cement and phosphate factories situated outside the BR and livestock herders. Meanwhile Bedouins on the lower western areas still depend on livestock grazing and farming activities in addition to some employment at Feynan ecolodge in the Dana BR.

Below is a summary of the composition of village tribes surrounding the reserve:

1. Saudeen clans (Busirah and Garandal towns)
Six clans live in both the Busirah and Garandal areas, and are given below:
Al-Rofou and Al-Zaidaneen are the biggest clans; Mazaydeh, Musaideen and Eyal-salman originate from Saudi Arabia; and Al-faqeer tribes originate from Palestine.

2. Atata Tribes (Dana and Qadesiah area)
Three tribes live in the Dana and Qadesiah area; they are Khawaldeh, Nanneh and Khsubah.

3. Bedouin Tribes (Wadi Araba area)
The lower western area around the reserve is inhabited by the Sadeen, Amarin and Rashaydeh tribes. It is also inhabited by the Azazmeh tribe originating from Palestine and later migrated to Jordan following the 1948 crises. Some of these families still roam the area looking for grazing sites and they usually live in tents. Grazing is the major source of income for this tribe although some have begun to work as farmers as well as seeking other locally available employment opportunities.

3.2 Uses of the biosphere reserve area and its surroundings

The studies conducted in the protected area indicate that throughout history this area was used by the population for mining, wood-cutting and grazing.

There are two groups of people who use the reserve and its surrounding area as a source of food for their livestock, they include:

1. **The villagers in settlements around the reserve**: these people make up the majority as Dana Biosphere Reserve is surrounded by several villages with most people working as farmers or livestock herders. Some of these people spend months inside the reserve for seasonal grazing with their livestock (Table 2).

2. **The Bedouins living in and around the reserve (in tents and caves):** most of them comprise the Azazmeh tribe who were originally Bedouin of the Negev area (in Palestine) as well as some families from the Sadeen, Amarin, and Rashaydeh tribes. These Bedouins live in tents in and around the reserve and use the reserve as a grazing area for their livestock. They try to set up their tents in the reserve or keep their livestock in caves especially during the winter.

Areas according to tribes	Livestock	
	sheep	goats
Busirah and Garandal (Saudeens)	3,225	823
Dana and Qadesiah (Atata)	3,166	796
Wadi Araba (bedouins)	345	5,852

Table 2. Numbers of cattle in the areas around the reserve according to information obtained for 2007.

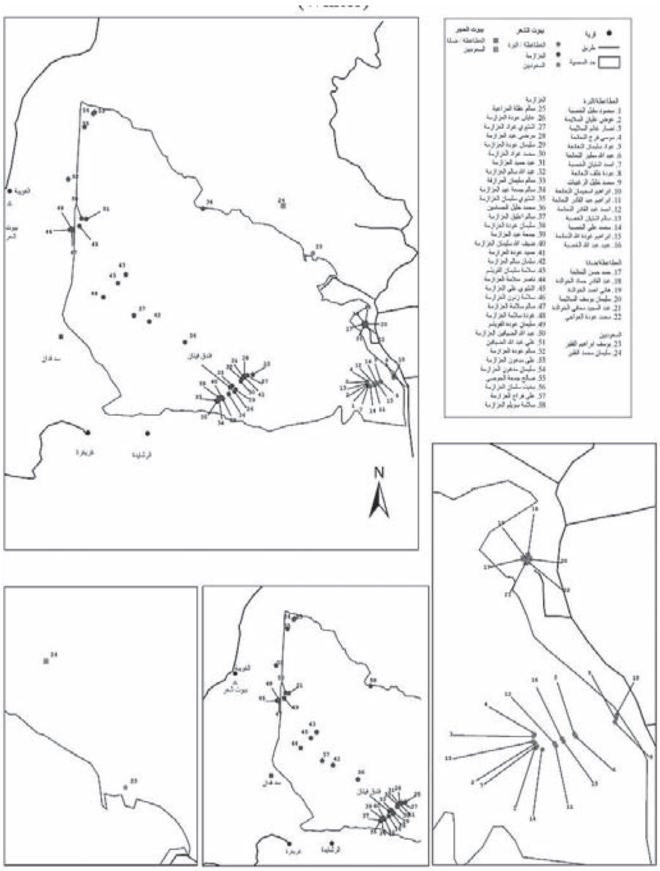

Figure 3. Site inhabitants during the winter.

Figure 3 shows the distribution of reserve inhabitants during winter, with the maximum number of inhabitants according to the seasons; the locations indicate the position of their Bedouin tents.

4. Conservation of natural resources, community development and scientific information

4.1 Conservation of natural resources

Actions to conserve natural resources have been conducted by the reserve and other local institutions on site. Both have different approaches to conserving natural resources; they are summarized below.

4.1.1 The Dana Biosphere Reserve approach

The reserve was established by The Royal Society for The Conservation of Nature (RSCN) for the purpose of conserving natural biodiversity in particular and natural resources in general.

The conservation of nature has been undertaken in Dana BR on the basis of scientific information gathered in the reserve and covers all areas of the reserve's management plan: biodiversity, flora, fauna, and socio-economic studies of the local community both inside and around the reserve. Using research methods, these studies have taken into consideration the experience and expertise of the local people on the research subjects in question.

Nature conservation has been undertaken in Dana BR using three main methods:

1. Raising awareness among the users of the natural resources, local stakeholders and government stakeholders:
   An outreach work plan was applied in the reserve for all the target groups in the local communities. The awareness-raising programmes have focused on the following areas:

- The sequences of unsustainable use of natural resources.
- Changing natural resource values by providing alternatives for the unsustainable uses of natural resources.
- The promotion of local actions for local, regional and global environmental solutions.

Many sectors have been targeted by awareness-raising programmes, these groups include:
- the heads of local clans and tribes;
- local government stakeholders;
- local farmers and livestock owners;
- local school children;
- women's groups in local communities;
- the local community in general.

2. Providing alternative resources to promote sustainable uses:
The reserve has established real life examples of alternatives to the unsustainable uses of natural resources, which are described below. Preventing local people from maintaining some of the unsustainable uses of natural resources has, in some cases, greatly affected both their livelihoods and the local economy and therefore a package of sustainable projects and alternative uses have been introduced by Dana BR in order to overcome this problem. These projects include ecotourism projects.

The reserve introduced ecotourism to the site in 1995; this was achieved through the establishment of three ecotourism sites in the reserve, which are considered the main tourism facilities inside the reserve and its surroundings. The three ecotourism sites are:
- Rumanah camp.
- Dana guesthouse.
- Feynan ecolodge.

3. Socio-economic projects
The reserve has launched many socio-economic projects in order to add value to the natural resources on site. These socio-economic projects are:
- the fruit drying workshop;
- the silver jewellery workshop;
- the goat leather tanning workshop.

4.1.2 Enforcement of conservation laws, regulations and nature resource use plans.

The Royal Society for the Conservation of Nature has been mandated by the government to establish and run the nature reserve and implement the hunting law in the kingdom. The reserve has introduced many plans i.e. the grazing plan, which has been adapted to local communities with their participation. The reserve is enforcing the implementation of the hunting law, grazing plans, a tourism zoning plan, and a forestry law within the reserve thus ensuring that the final step in conserving the natural resources is accomplished.

4.1.3 Other institutions' approach

Many other institutions have further contributed in the effort to conserve the natural resources. These institutions include:
- the local department of the Ministry of Agriculture: through implementation of the agriculture and forestry laws, and the provision of some efforts in conservation soil.
- the local municipalities: through the support of some water management systems; although not highly efficient, these systems still contribute toward water conservation.

4.2 Community development

The government in general has conducted and provided many services to the local communities in the area. The municipalities have provided electricity, paved roads, and established sewage drainage systems. The Ministry of Education has established schools and implemented education programmes for all the children and teenagers from the local communities. In addition, the Ministry of Agriculture has established many tree nurseries and veterinary stations to provide services to local farmers and livestock owners.

The reserve employs 85 people in permanent jobs from among the local community, thirty of which are occupied by women; it is hard for women to find jobs in local communities outside the government sector. The reserve has also implemented many socio-economic projects to assist in community development. These projects have been divided into two streams and are described below.

4.2.1 Socio-economic projects run by Dana BR

These projects are managed solely by the reserve, and are divided into two types:

1. Ecotourism projects

Ecotourism has made a good contribution to the local economy; financial statistics reveal that each of the three ecotourism sites, mentioned previously, brings in more than USD 40,000 for each one of the three main communities around the reserve. Also ecotourism, through its social responsibility programmes, has introduced other cultures and people to the local community thus helping to enrich their local knowledge and experience.

2. Socio-economic production workshops

Buying organic crops from the orchard gardens of Dana village and other villages around the site for the fruit drying workshop contributed to the development of the local economy. Also, the silver jewellery workshop uses polished stones produced by the local women's cooperative to make jewellery, Dana BR is supporting the inititiave by buying 80% of their products. The leather tanning project also buys goat hides from the Bedouin communities as they have the highest numbers of livestock in and around the reserve.

4.2.2 Socio-economic projects run by the local community and Dana BR

Many other projects have been developed with local communities' cooperatives and charitable societies, these projects have a budget of USD 250,000 and have covered the following areas:

- Water irrigation systems in Dana village.
- Soil conservation in the terraced garden of Dana Village.
- Small scale ecotourism initiatives.
- Medicinal plants.
- Herbal tea production.
- The traditional production of sheep and goats milk products.

4.3 Scientific information

Scientific studies and monitoring programmes have been conducted on site to ensure that the conservation effort and the community development projects are integrated in the policy of natural resource sustainability. Many monitoring programmes are providing the reserve management with scientific information and include:

- Monitoring weather conditions using data from the reserve's meteorological station.
- Soil erosion monitoring programme.
- Water monitoring programme.
- Breeding raptors monitoring programme.
- Lesser kestrel monitoring programme.
- Ibex monitoring programme.
- Regeneration of key trees in the reserve.
- Information gathering for fauna log data.
- Information gathering for flora log data.

Scientific information has been gathered through the application of many methodologies and approaches, and are as follows:

4.3.1 Assessment methodology of flora survey in Dana BR

Two principal methods can be used in this survey; route transects and survey plots, as described below:

Route Transects

This method is applied using the following steps:

1. Route transects are designed to cover all habitats in the reserve area. Route transects cover runoff valleys, small side valleys, mountain tops, water springs, granite hills, sand dunes and sandstone hills.
2. The locations of the route transects are identified by locating starting points that lead into accessible mountain paths. This should be decided by visiting the different mountains and studying the mountain topography on maps.
3. The route transects should be covered on foot.
4. The start and end coordinates for each of the route transects are taken.
5. At the end of the day, all the information collected should be compiled and recorded on datasheets. The final result should provide a datasheet for each route transect which includes all the recorded information. This information includes:
   - Start and end transect coordinates.
   - Plant species recorded.
   - Plant specimens collected.
   - Faunal observations (scats, pellets, footprints, animal sightings, etc).
6. The specimens collected should be dried and kept in plant presses.

As a final step, it is very important to conduct interviews with the local people in order to garner their opinion on subjects covered by the survey as well as discuss the obtained results with them.

Plots

This method is applicable mainly to wide valleys and open areas. The main aim of this systematic method is to define the different vegetation communities and the way these communities overlap.

1. The number and distribution of plots within the study area should be assigned to cover the area and be representative.
2. A fixed distance (e.g. 2 km) should separate two plots with the same axis.
3. In each plot, the following information is recorded:
   - Plant species.
   - Number of individuals of each species.
   - Percentage coverage of each species.
   - Phenology of species recorded (vegetative nature, flowering, fruiting, and seed-setting).

Habitat description includes:

- Soil type.
- Soil texture.
- Rock type.
- Rock cover.
- Signs of grazing and/or woodcutting.
- Fauna presence (pellets, scats, burrows, etc).
- Presence/absence of car tracks.

4.3.2 Assessment methodology for breeding bird populations

Three main survey techniques for determining breeding bird populations can be considered for use in this survey; a brief description of each is outlined below. However, each has its limitations and is therefore more suited to some areas or types of habitat than others:

1. *Territory mapping*: this consists of making repeat visits, usually ten, to a given area over the course of the breeding season. During each visit, all bird registrations (sight and sound) are recorded on a large scale map using a set of standardised symbols to represent each species and each type of activity. At the end of the breeding season all records for each species are combined on single species maps, analysis of which gives the number of breeding territories.
   Territory mapping is a very time-consuming process because of the number of visits that need to be made to

each study plot and so is best suited to small study areas. It requires experienced observers both for the fieldwork and for the interpretation of the species' maps.

2. *Line transect:* here an observer walks a set route and records all bird registrations as well as the perpendicular distance of each on either side of the line of the route. Rather than exact distances, registrations are usually divided into distance bands e.g. 0–25 metres, 26–50 metres. A mathematical formula can then be applied to the results to calculate the density of each breeding species.

   In practical terms, line transects rely on the observer walking at a constant speed in each survey plot and being able to accurately determine the perpendicular distance of each registration. Several theoretical assumptions also apply such as whether all birds present are detected by the observer, and whether all birds are equally detectable. If any of these assumptions are violated, the results become less reliable. As with territory mapping, an observer experienced in both bird identification and distance assessment is required.
3. *Point count:* this is effectively a line transect of zero length. The observer stands at a given point and records all bird registrations during a set period, again allocating each registration to a distance band. As with a line transect, a formula can be applied to calculate bird densities and, again, there are several theoretical assumptions which are made and should be fulfilled in order for the results to be valid. It is very important as a last step to conduct interviews with local people in order to garner their opinion on subjects covered by the survey and discuss obtained results with them.

4.3.3 Assessment methodology for reptiles survey

The most common and applicable methodology for surveying reptiles is the line transect methodology.

1. Special representative line transects should be allocated in the reserve; take note to include all habitats and microhabitats in the survey.
2. The distance of these transects should be covered on foot and at a constant speed.
3. Any noted species should be identified and recorded on a special data sheet.
4. A full habitat description should be obtained for each observation.
5. The line transect should be carried out at day and night to cover nocturnal species (snakes and agamas) and diurnal species (skins, lizards, etc).

4.3.4 Assessment methodology for mammals

Depending on the final objectives of the study in question, a specific methodology should be applied.

Method One: Surveying for animal signs

It is designed to provide information about the presence and distribution of species.

1. Spoor transects to be distributed within the reserve at different sites and covered once daily by the research team.
2. Field guides are used to identify footprints (e.g. Liebenberg).
3. Scats are collected when found and identified.
4. A special data sheet should be designed to have the following notes and observations: date, time, track, any sighted species, behavior.

Method Two: Cage trapping

Cage traps are used in two concurrent programmes; opportunistic trapping to establish and confirm presence of a species, and a Capture-Mark-Recapture Programme to assess populations of more abundant species.

1. Use cage traps of 100cm x 40cm x 40cm or 100cm x 50cm x 50cm.
2. Use various bait types like fresh meat, canned sardines, eggs.

3. Traps should be checked daily. It is recommended to check them as frequently as possible to minimize the length of captivity.
4. Identify captured animals.
5. Animals captured should be weighed (using a spring balance), sex-determined, aged and photographed.
6. Collect hair specimens from captured animals for DNA analysis.
7. Morph metric data should also be collected.

Also many other procedures could be used to study the distribution, relative abundance and behavior of fauna in the Dana BR, some of these methods applicable in the reserve are listed below:

- Photo trapping.
- Soft-catch trapping.
- Spot-light trapping.
- Tranquilizer gun.
- Spoor transects.
- Baiting stations.
- Hair trapping.
- Interviews with local people.

5. Practices implemented for soil and water conservation

The work on site covering soil and water conservation is split into two parts: the first involves soil and water monitoring programmes and the second involves soil and water conservation programmes, both of which are outlined below.

5.1 Water conservation

5.1.1 The monitoring of water quality in the site

A monitoring programme has been established and enhanced using more accurate digital equipment bought through the SUMAMAD project, as described below.

Introduction

Water quality is a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose. Water quality is affected by a wide range of natural and human influences, and among the natural influences affecting both quality and quantity of water availability are geology, hydrology, watershed characteristics (i.e. vegetation and topography), microbiological activity and climatic factors (i.e. precipitation, temperature).

Effective monitoring of water quality is essential, especially the groundwater basin that provides the water supply for plants, animals and sometimes people in the reserve. So, groundwater monitoring programmes should be implemented to ensure a safe and healthy water supply.

A baseline survey of the permanent water bodies in Dana BR was conducted in late 1995. Results concluded that the water bodies were generally of satisfactory quality at that time. It is important that the water bodies be periodically monitored to enable the Dana management to monitor quality degradation as early as possible, and to record fluctuations in water conditions.

Objectives

The development of the Water Body Monitoring Programme should answer the following questions:

- What is the overall quality of water?
- To what extent is water quality changing over time?

Materials

The materials needed include a GPS, compass, metre tape, a digital electrometer kit that measures pH, electrical conductivity, temperature, chlorine, oxidation reduction potential, a digital colorimeter that measures nitrate, hardness, calcium, magnesium, dissolved oxygen, phosphorus, copper collection vials, beaker, cylinder, de-ionized water, washing bottle, chemical reagent, pipette, vehicle, and recording sheets.

Data sheet

Recorded information includes the location of water bodies, spatial and temporal characteristics, topography and surroundings, and hydro-chemical data. Information on the characteristics of the water body itself is collected in the following categories: source, movement, duration and type of water body, slope, aspect, width, depth, bottom characteristics, type of algae, water colour, sediment colour, odour, and level of eutrophication.

The surroundings of the water body are defined by vegetation description, animals observed and spoor present, soil type, and percentage of surrounding vegetation, soil and rock.

Climatic data includes the time since the previous rain episode, and the general weather on the day the water body was observed. Hydro-chemical parameter values are determined in the field and recorded on the data sheet. Some socio-economic issues are investigated by recording information on water use by local communities and populations, and the degree of human impact.

The main measured characteristics of water are also recorded and include: pH, electrical conductivity, temperature, hardness, calcium, magnesium, dissolved oxygen, chloride, nitrates and oxygen reduction potential.

Study area

All the water bodies within the Dana Biosphere Reserve have been located and monitored as well as another three springs located on the edge of the reserve (Figure 4).

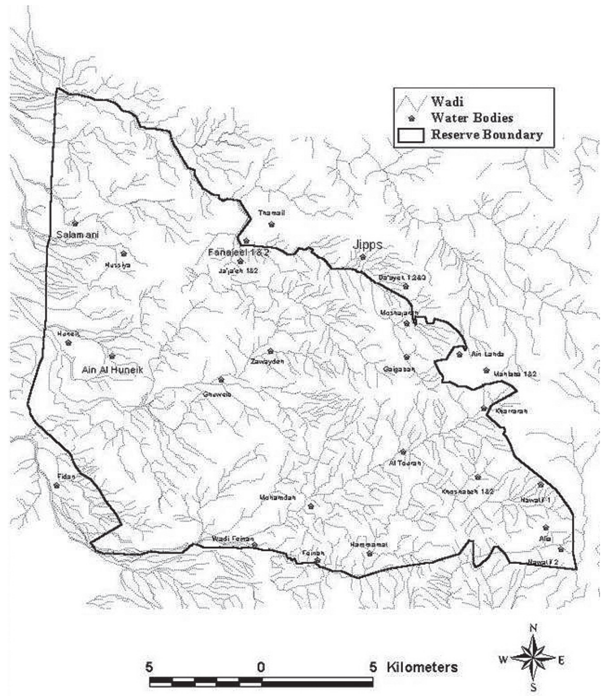

Figure 4. Map of water springs.

Method

A water testing digital instrumental device is used to measure pH, electrical conductivity, temperature, hardness, calcium, magnesium, dissolved oxygen, chloride, nitrates and oxygen reduction potential. The detailed specification of each water parameter procedure is given below.

Temperature

Introduction: temperature is an important variable because all living organisms such as amphibians and many plants living in certain water bodies can only survive within certain temperature ranges. Temperature has a direct relationship with the amount of dissolved gases in water, mainly dissolved oxygen; as temperature increases the solubility of oxygen decreases.

Method: several types of instruments measure temperature such as a mercury thermometer and an electrochemical instrument (electrode). For this monitoring programme an electrode method (ExStik®CL200A – EXTECH brand) was used. Temperature is measured directly by inserting the electrode into the sample, the result is obtained directly from the digital temperature display screen.

pH

Introduction: pH is a measure of the degree of acidity or alkalinity of a solution as measured on a unit less scale (pH scale) of 0 to 14.

The midpoint of 7.0 on the pH scale represents a 'neutral' solution, which is neither acidic nor alkaline. Numbers below 7.0 indicate acidity; numbers above 7.0 indicate alkalinity. For each pH unit the acidic or basic effects increase by a factor of 10. The standard pH level for safe drinking water should be between pH 6.5 and 8.5.

Method: pH can be measured by indicators such as indicator strips, electrochemical instrumention (electrode) or colorimeters. The electrode method was used for this particular monitoring programme (ExStik®CL200A). The result is obtained by direct digital reading using the attached pH electrode.

Hardness

Introduction: water hardness is a measure of the concentration of the multivalent cations (positively charged particles) in the water, but primarily it is equivalent to the calcium and magnesium concentration in water. Hardness is typically reported as mg/L as $CaCO_3$ (calcium carbonate), hardness classification: soft: 0 to 17 mg $CaCO_3$/L; slightly hard: 17 to 60 mg/L; moderately hard 60 to 120 mg/L; hard 120 to 180 mg/L; and very hard > 180 mg/L.

Method: there were several methods used to determine hardness in the previous monitoring programme, Dana research centre used a chemical indicator kit, today a new method for determining hardness will use a colorimeter instrument (DR890 – HACH brand). Simply follow the steps in the (DR890) manual for measuring $CaCO_3$ hardness.

Electrical Conductivity (EC)

Introduction: the capacity of a substance to conduct heat or electricity at a specified temperature, the conductivity or specific conductance is directly related to the concentration of dissolved substances; it's a cumulative parameter for the ionic concentration of a solution. The more salt, acid or alkali contained in a solution, the greater its conductivity. So indirectly it can reflect the concentration of dissolved substances in a specific sample. The unit of measuring conductivity is the Siemens per metre (S·m-1) (formerly called mho), which is the reciprocal of resistivity (1 divided by resistivity). Naturally occurring waters such as drinking water or surface water have EC in the 100–1000 µS/cm range.

Total Dissolved Solids (TDS) can be calculated using the following formula:
TDS (mg/l) = EC(µs/cm) * 0.67

Method: for this particular monitoring programme an electrode method (ExStik®CL200A) was used for measuring electrical conductivity. This can be done by direct digital reading using the attached electrode.

Oxygen Reduction Potential (ORP)

Introduction: the OPR potential is a measure of the reducing or oxidizing strength of a solution. A negative potential value means that the solution has a reducing action compared with the standard hydrogen electrode. A positive value means that the solution has an oxidizing effect. OPR measurement is mostly used to check the denitrification of wastewater or water disinfection.

Method: like pH, OPR can be measured by electrochemical instrument. An electrode method (ExStik®CL200A) was used for measuring OPR. This can be done by direct digital reading using the OPR-attached electrode.

Dissolved Oxygen (DO)

Introduction: dissolved oxygen is the volume of oxygen (O_2) dissolved in a certain liquid. Measured water quality indicates the free oxygen dissolved in the water essential for respiration processes. Oxygen is required for the process of purification in water bodies, water quality begins to deteriorate when all oxygen is used up; 'black water' is a measure of this deterioration. The actual oxygen concentration depends on a number of factors such as temperature, air pressure, and oxygen consumption by microorganisms. For example, at a temperature of 20°C and atmospheric pressure at 1013 mbar, saturated water contains about 9 mg/l oxygen.

Method: for this particular monitoring programme a new method for determining DO will use a colorimeter instrument (DR890) related to the HACH brand.

Chloride (Cl)

Introduction: chloride is one of the major anions found in water and wastewater. High chloride content causes damage to water pipes and can have harmful effects for plants. The recommended maximum contaminant level is 250 mg/L as the chloride ion imparts a salty taste to the water. If calcium and magnesium ions are present, the chloride ion may not impart a salty taste until in excess of 1,000 mg/L.

Method: there are several methods for measuring chloride content including using a chloride kit and an electrode method. In this particular monitoring programme the ExStik®CL200A electrode was used. The result is obtained by direct digital reading using the attached electrode.

Nitrates

Introduction: nitrogen is one of the most vital elements required by biological systems and is considered a limiting factor in primary productivity in aquatic environments. Higher concentrations are often associated with the overuse of nitrogen fertilizers and manure, intensive livestock operations, and/or leakage from septic tanks or municipal waste. Nitrates can indicate algal bloom production. High concentrations of nitrate and phosphate cause outbursts of algal production, which triggers eutrophication processes in the water body leading to decreased oxygen levels.
The presence of nitrate indicates high oxygenation potential while ammonia and nitrite are associated with reducing environments.

Method: there are several methods for measuring nitrate content including the nitrates kit electrode method and colorimeter method. For this particular monitoring programme, the nitrate determining method will use a colorimeter instrument (DR890 – HACH brand).

Phosphate (PO_4)

Introduction: like nitrates, phosphates are found in high concentrations in nature and are considered an important element for biological systems. In surface waters, phosphate is a plant nutrient needed for growth and is a vital element for plant and animal metabolism (hence its use in fertilizers). Excess phosphates cause extensive algal growth called 'algal blooms', which are a symptom of eutrophication leading to decreased oxygen levels in the water body.

Method: like nitrates, this particular monitoring programme for determining phosphate will use a colorimeter instrument (DR890 – HACH brand).

Monitoring in 2007 is performed using new digital equipment unlike the previous monitoring programme sessions. Therefore comparisons with the previous sessions findings may prove inconsistent. Moreover, it is the first session using digital readings for all water variables.

5.1.2 Water management activities in the orchards of Dana Village

Activity introduction

Water from the three springs in Dana village is used to irrigate a total area of 40 ha of fruit farms. The productivity of these farms is low because of the limitations of the present water management system. To overcome this problem, an effective water management system was established and implemented with full cooperation from the Dana Charitable Society (the only charitable society in the village). This was achieved through a participatory approach with farmers in order to benefit from their indigenous knowledge and experience.

Through the SUMAMAD project, the BR conducted the following activities:

- A workshop was held for the farmers in the village on the best way of irrigating the terraced gardens in Dana village. The workshop was held in the reserve complex and was facilitated by an agricultural engineer specializing in irrigation systems.
- The installation of more than 500 m of pipes between channels for the construction of an efficient irrigation system.

Activity

The water irrigation system in the village orchard gardens were developed and enhanced with many of the channels prepared and maintained. The farmers' local knowledge was very important to determine the best arrangement and routes for the channels to follow in order to obtain the most efficient arrangement, which involved the construction and maintenance of 360 m of channels in the orchard gardens of Dana village. The main beneficiaries were the farmers who owned the gardens which now benefit from a greater share of water thanks to the reduction of water loss through the system. Nineteen farmers benefited from this channel system.

Moreover, the difficult terrain in the area, whereby most orchards are situated on highly sloped lands, require that the following soil conservation activity is carried out.

5.2 Soil conservation

5.2.1 The monitoring of soil erosion in the site

A soil erosion monitoring programme has been established by part of the SUMAMAD project team with financial support from the SUMAMAD project in the southern aspect of Rumanah Mountain in the heart of the reserve's core area; this area was chosen because the juniper forest situated here is dying back. The monitoring programme for this year is described below.

Introduction

One of the major processes evident throughout the Dana Biosphere Reserve is erosion, which is the detachment and movement of topsoil caused by wind action and water flows. It is considered to be the principal factor affecting the decline of vegetation cover in some parts of the reserve particularly in the Mediterranean and semi-arid areas.

The monitoring programme objectives:

- Determine the soil erosion rate at the Rumanah western slopes in Dana Biosphere Reserve.
- Provide recommendations for future research and monitoring programmes.

Material and methods

Materials

An iron measurement stick, measuring tape, GPS, camera, and data sheet.

Methods
The plot method was used to identify the rate of soil erosion on the southern aspect of Rumanah Mountain in Dana Biosphere Reserve. Five rows were established each with three plots. Every plot is composed of 10m x 10 m plots with a distance of 10m between them. Paint was used to create the borders of each plot and an iron stick was used to mark the centre after checking the coordinates using a hand-held GPS. A ten metre distance separates each row. A 100 cm iron measurement stick is only used on the central plots of each row (Figure 5).

The height distance between the ground and the top of the iron measurement stick is 70cm, with the first 30 cm of the stick embedded in the soil. Labels were attached and include the height, date and number of the stick for future monitoring programmes.

Plots were studied by recording the different components, habitat description, altitude, slope, rock type, soil type, and bare rock percentage. Two photos from the northern edge of the plots were taken.

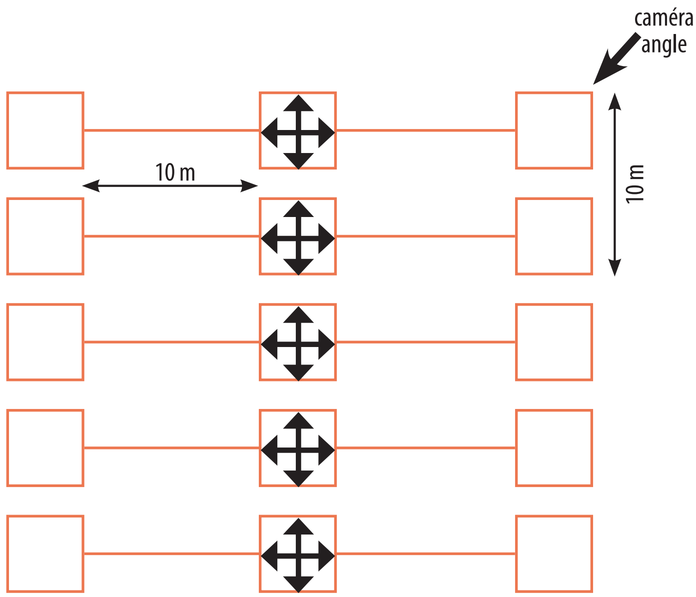

Figure 5. Design of the plots.

Soil conservation activity
Because of the difficult terrain of the area, most of the orchards are situated on highly sloped land, so the following soil conservation activity was carried out:
A raising-awareness programme was carried out with and for the farmers. This programme concentrated on the use of stone terraces in order to conserve the soil in the orchard gardens. A total of twenty farmers attended this workshop and were able to enhance and develop their knowledge in this domain.

Demonstration of traditional traces for soil conservation
The use of terraces for soil conservation and for the purpose of restoring and rehabilitating lands for agricultural purposes was carried out in cooperation with the Dana Charitable Society. This demonstration has been set up at the entrance of Dana village where it can be shown to visiting groups. This also applies with another GEF/small grants project carried out in the reserve to develop the administration needed for organic farming on the same site.

6. Income generating activities to diversify the economic base at household levels

Dana BR has many income-generating activities such as a silver jewellery workshop, a fruit drying workshop, and a leather tanning project. New income-generating activities were developed through the SUMAMAD project involving the use of olive oil in the production of olive oil soap, described below.

6.1 Olive oil soap production workshop
In Dana village and other villages and towns around the

reserve people own many olive farms that are reputed to produce the best olive oil in southern Jordan. All these olive trees are grown without the use of pesticides and fertilizers, however, the owners are suffering many marketing and price fluctuations despite the very good quality of their olive oil. Part of the olive oil produced by local farmers will be used to produce high quality olive oil soap in a workshop located within the Dana Biosphere Reserve Centre. The soap is chemical-free and produced in a traditional way. The soap pieces have inscriptions inspired from animals and plants found in Dana BR. The product will be used in all the reserve's tourist sites to help promote the soap.

Olive oil soap was developed from the second year of SUMAMAD project implementation (Figure 6), but in reaction to the rise of other olive oil soap products on the market in Jordan, new themes and concepts were developed and added to our primary soap product.

After exploring the market for similar products, the question was raised as to whether our prototype has good competitive characteristics compared to other olive oil soap products. Following consultations with marketing

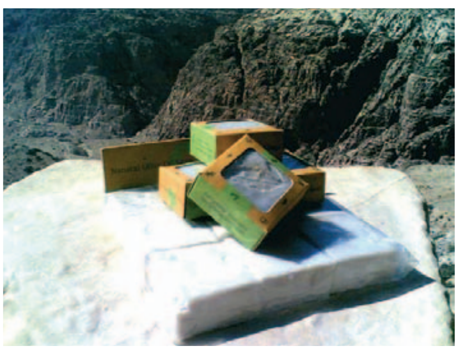

Figure 6. Olive oils soaps produced in the workshops in Dana BR.

and local soap-making experts, the following points for additional product development were concluded:

- The way in which olive oil soap is presented and sold.
- The natural ingredients used in soap production.

Working with various professional local experts with very good knowledge of traditional olive oil soap production, good progress was made to attribute new shapes and characteristics to the soap. The main new developments were:

- A new presentation was developed whereby visitors are able to carve out soap directly from a main block. Other shapes and dimensions were also developed.
- A new herpes plant has been introduced.
- A prototype of olive oil soap with lemon has been developed; an acidic soap found to be very good for skin care (Figure 7).

Figure 7. The skin care range of olive oil soaps.

The local response to this project was very positive and two young women were recruited to the project. A large quantity of olive oil is bought from the local farmers to produce the soap. The response of the local people is in addition to the positive responses received from previous initiatives carried out in Dana BR and this has increased the local appreciation towards the conservation of natural resources.

7. Results obtained

7.1 The results of the socio-economic study

One of the main socio-economic surveys, supported by the SUMAMAD project, was carried out on site and covers all the communities in the western part of Dana BR (Feynan, Graigrah, Al-Rashaydeh and Al-Guaibeh). A summary of the study's findings is shown in Table 3 and Figures 8 and 9.

Context	Al Rashaid Rashaideh	Graigrah	Feynan	Al Guaibeh
Social context				
Estimated number of families	31	116	10	40
Estimated population	NA	1,500	NA	500
Social matrix	Al Rashaideh (Hwaitat)& Azazmeh	Ammarien, Saideen & Azazmeh	Ammarien, Saideen & Azazmeh	Al Kharangeh & Al Hasanat
Schools	One elementary school	One elementary school	One elementary school	One elementary school
Services	A health care centre is under construction	Municipality health care centre, two NGOs, and six shops	None	None
Economical context				
Unemployment	66.10%	76.60%	74.20%	85.40%
Main economic activities	Pastoral and limited agriculture	Growing agri-business, pastoral and limited services	Pastoral	

Table 3. The socio-economic context of the communities in Dana BR.

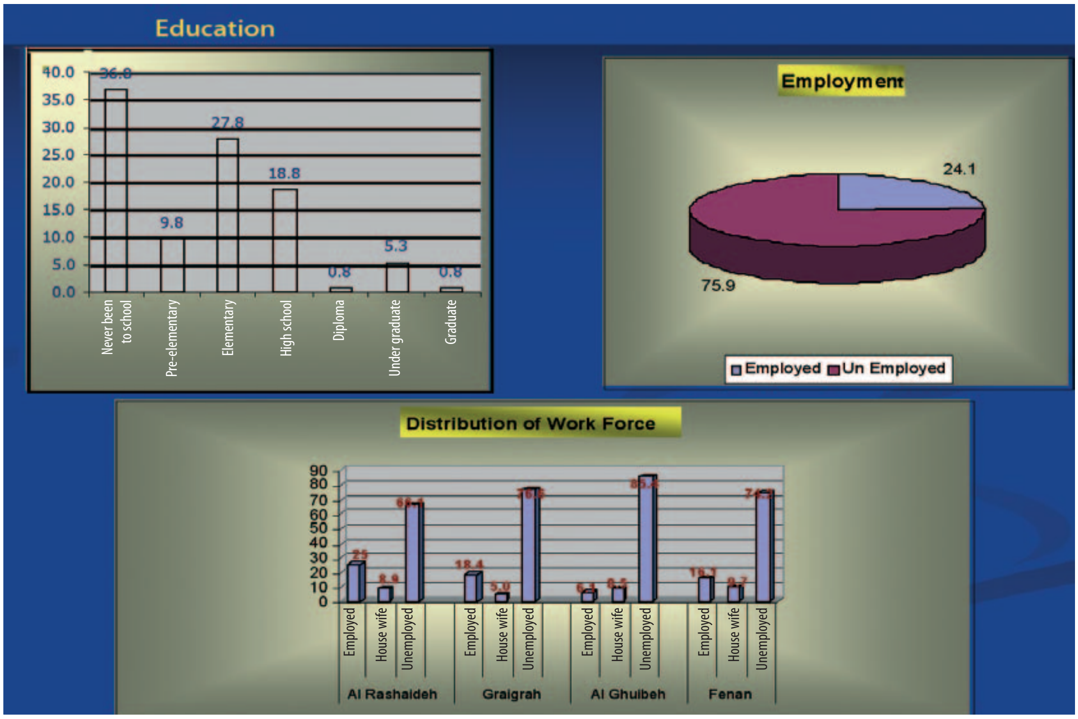

Figure 8. The level of education and employment prospects in the communities of Dana BR.

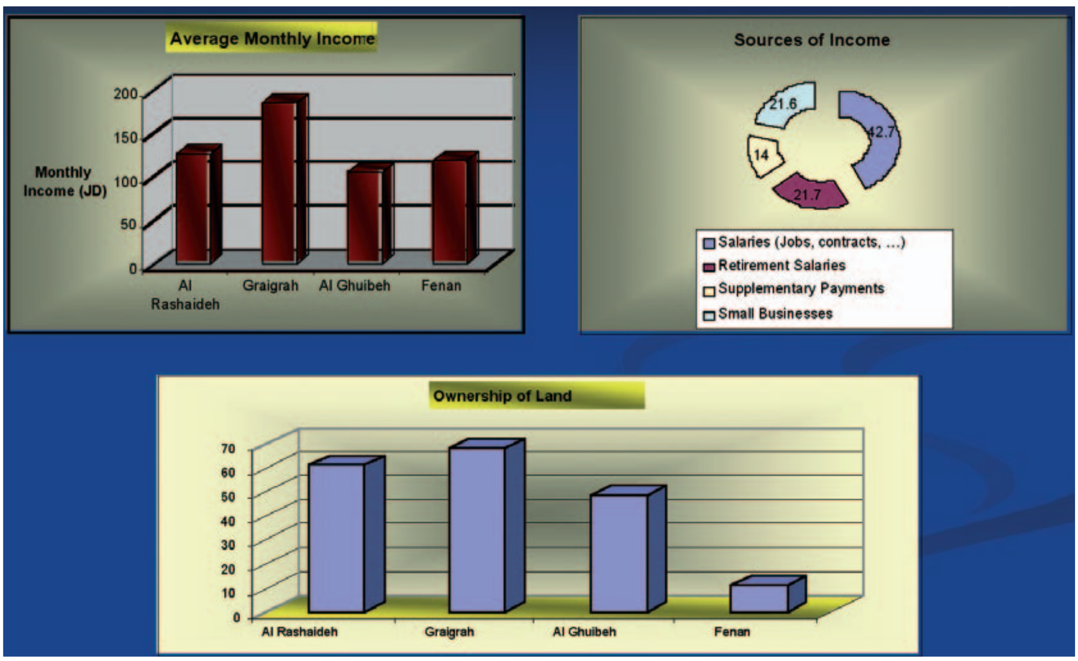

Figure 9. Income average and sources.

Water body	pH	ORP (mV)	Conductivity (μS)	Temperature (° C)	Phosphate (mg/L)	Nitrate (mg/L)	Chlorine	DO (mg/L)
Mahlebeh	7.77	325	550	19.3	0.1	5.5	0.0	6.1
Um-Doodeh								
Umel Fanajeel	7.7	145	355	26.5	0.85	0.7	0.0	6.5
Eth-thamayel	6.93	141	511	23.5	0.32	3.1	0.0	7.5
Je'ja'eh	7.38	121	286	25.2	0.53	5.5	0.0	7.38
Sayl Dana-up	7.5	115	644	22.1	0.49	3.4	0.0	6.0
Sayl Dana-down	7.56	196	650	24.4	2.67	3.7	0.0	5.9
Ain Khaled	7.14	104	965	20.2	0.32	1.3	0.0	6.1
Ez-Zrayb	7.82	129	690	25.1	0.52	0.2	0.0	7.3
Lahthah	7.73	141	511	19.8	0.17	5.5	0.0	5.9

Table 4. Abiotic parameters of water quality carried out in the summer of 2007.

7.2 The results of the water monitoring programmes

7.2.1 The monitoring of water quality in the site

The preliminary results from monitoring, carried out in the summer of 2007, are given in Table 4.

Monitoring in 2007 was performed with new digital equipment unlike earlier monitoring programme sessions, therefore it might not be judicious to compare this session's findings with previous findings as the results were not as accurate and have low credibility. Complete results with discussion and recommendations will be provided in the early part of 2008.

7.3 Results of the soil erosion monitoring programme

Table 5 presents the preliminary results of vegetation compositions in the plots, monitored in 2007. The results of this monitoring programme will be clear when comparisons between years is carried out.

7.3.1 Discussion

Rumanah Mountain in Dana BR is greatly affected by soil erosion. This monitoring programme was thus designed to follow a long-term monitoring programme in order to calculate the rate of soil erosion and any changes in vegetation composition which will influence soil erosion and change the structure of this area.

The percentage of vegetation cover will be used to estimate the correlation between the vegetation cover and the rate of soil erosion; this will guide the reserve management in maintaining the critical percentage of vegetation cover in the area so as to prevent soil erosion. Results will be expected from the data taken during monitoring, and when compared with future results.

Slope measurements will be used to show its relationship with soil erosion; the iron measurement stick will help demonstrate the rate of soil erosion. Photos will be used to show the changes in the land structure of each plot, taking into consideration the need to capture images from the same northern edge of

Date	Plot number	Vegetation composition	% of juniper
16-4-2007	1	*Artemisia Siberia, junipers phoenica,Urginea martime, Salsola vermiculata, scabiosa eremophila, Euphorbia hierosolymitana, Ferula coummunis, Helianthemum ledifolium, Senecio flavus, Anthemis pseudocotula, Hordeum glaucum*	0
	2	*Artemisia Siberia, Junipers phoenica, Urginea martime, Salsola vermiculata,Euphorbia hierosolymitana, senecio flavus, Anthemis pseudocotula, Hordeum glaucum, Angalis spinosa, fagonia mollis.*	0
	3	*Junipers phoenica, Ferula coummunis, Euphorbia hierosolymitana, Anthemis pseudocotula, Urginea martime, Ephdra ciliate, Bromus tectorum, Hordemum bulbosum, Avena sterilis*	100
	4	*Junipers phoenica, Urginea martime, Fagonia mollis, Anthemis pseudocotula, Ferula coummunis, Erucaria boveana, Avena sterilis.*	62.5
	5	*Junipers phoenica, Ferula coummunis, Anthemis pseudocotula, Erucaria boveana, Euphorbia hierosolymitana, Urginea martime, Angalis spinosa, Retama raetam, Noaea mucronata.*	86
	6	*Junipers phoenica, Erucaria boveana, Senecio flavus, Bromus tectorum, Ferula coummunis, Centoria aegyptiica, Urginea martime, Euphorbia hierosolymitana, Anthemis pseudocotula, Fagonia mollis.*	75
	7	*Junipers phoenica, Ferula coummunis, Erucaria boveana, Helianthemum ledifolium, Centoria aegyptiica, Bromus tectorum, Avena sterilis.*	67
	8	*Junipers phoenica, Erucaria boveana, Bromus tectorum, Stipa capensis, Urginea martime, fagonia mollis, Ferula coummunis, Noaea mucronata, Euphorbia hierosolymitana, Anthemis pseudocotula, Centoria aegyptiica.*	80
	9	*Junipers phoenica, Ferula coummunis, Erucaria boveana, Anthemis pseudocotula, Euphorbia hierosolymitana, Bromus tectorum, Noaea mucronata*	78
	10	*Junipers phoenica, Ferula coummunis, Erucaria boveana, Retama raetam, Veliza rigida, Noaea mucronata, Bromus tectorum.*	0
	11	*Junipers phoenica, Ferula coummunis, Erucaria boveana, Bromus tectorum, Retama raetam, Noaea mucronata.*	50
	12	*Junipers phoenica, Ferula coummunis, Euphorbia hierosolymitana, Erucaria boveana, Bromus tectorum, Ephedra alte.*	20
	13	*Junipers phoenica, Ferula coummunis, Stipa capensis, Teucorium capitatum, Phagnalon rupstre,*	0
	14	*Junipers phoenica, Ferula coummunis, Erucaria boveana, Allium ampeloprasum, Noaea mucronata*	50
	15	*Junipers phoenica, Artemisia Siberia, Noaea mucronata, Ferula coummunis, Erucaria boveana, Atractylis carduus, Adonis dentate.*	33

Table 5. Plant compositions in the test plots.

the plots. Future data analyses will show the relationship between habitat structure and the soil erosion rate. Combining this data with future data will give us a clearer idea of the reasons behind soil erosion and how it affects the rate of erosion in the area, which in turn will guide the reserve management towards problem-solving.

7.4 Results of the income-generating activities

Positive results were obtained from the income-generating activities (olive oil soap workshop):

- The return on income has increased for the olive oil farmers in Dana village and surrounding villages.

- The final product demonstrates the very good links between: traditional manufacturing, market needs, and income-generation for and by the local people. Many other small and medium projects have visited the site to see the development of the project themselves and to learn from our experience.

8. Recommendations for sustainable dryland management

Recommendations in this section are divided into two groups: the first set of recommendations corresponds to specific activities carried out on site, and the second set of recommendations are general recommendations that concentrate on improving the sustainable management of drylands.

8.1 The specific recommendations

8.1.1 From the socio-economic study of communities in the western part of Dana Biosphere Reserve.

Supporting the farmers with technical assistance in terms of agricultural activities (land use, plant types), especially in Al-Rashaydeh, Graigrah and Ghwebbeh villages, will offer the population additional sources of income.

- Revival of the charitable society and cooperatives with handicrafts training for women, while providing tourism and agricultural opportunities for men; the community does not accept men and women working alongside each other.
- Encourage and cooperate with the municipality's Health Ministry to monitor the area in terms of clean water resources for irrigation and consumption.
- Establish support from the local community with revolving fund programmes that provide loans to develop small income-generating projects in agriculture and livestock, which will minimize poverty and increase employment opportunities in the area.
- Share the decision-making and outreach programmes with stakeholders and key people in society in order to succeed.
- Because grazing and nature conservation are very important to the people in the area, the RSCN (as a key player) should activate this role through outreach and public awareness programmes, and with clear procedures on how to obtain grazing permits.
- Suggest mitigation measures to anticipate the socio-economic effects of the intended development on the local communities located within the direct and indirect zones of effect.
- Implement recommendations to enhance local understanding and appreciation for:
  - the need for nature conservation;
  - the need for local community involvement in nature conservation;
  - the need for RSCN involvement in the area;
  - the benefits and drawbacks of the intended project.

8.1.2 From the socio-economic study of Dana village and Al-barra area inhabitants

The following are suggestions for parameters to monitor the achievements of Dana BR (the project site) in developing a policy that integrates nature conservation and at the same time helps the local community.

The indicators are divided into two groups:

Replacing the activities that harm biodiversity

- The target population is earning a sufficient income to compensate for the restrictions imposed by the reserve's personnel.
- The household income of the target group is less dependent on non-sustainable land use practices.
- The number of livestock is decreasing.

Improving attitudes towards biodiversity conservation

- Economic and social development in the community is increasing.

- Community income meets or exceeds income prior to the establishment of the protected area.
- Community income is more diversified with less dependency on unsustainable land use practices.
- Villagers believe that the reserve has had a positive impact on their economic situation.
- Villagers believe that the alternative income opportunities adequately replace their income from unrestricted grazing.
- Women are increasingly integrated into formal economic activities.
- Collective community skills, knowledge and leadership, which is needed to develop the economy, are increasing.
- Villagers express conservation-friendly attitudes.
- Villagers believe that grazing restrictions are necessary to conserve wildlife.
- Villagers believe that conserving wildlife in Jordan and their area is important.
- Villagers value sources of income from sustainable land-use.
- Grazing violations are decreasing.

The local population accepts the existence of the reserve:

- Villagers believe that the reserve has had a positive impact on their quality of life.
- Villagers know the role and goals of the reserve.
- Villagers' attitudes toward the reserve are becoming increasingly positive.
- Villagers believe that changes in the community as a result of involvement by the reserve are positive.
- Villagers accept the role of RSCN in their community.
- Villagers commit fewer hostile acts against the reserve.
- Villagers believe they can trust the reserve's personnel.

8.1.3 Recommendations for soil erosion monitoring programmes

- A monitoring programme should be followed every three years to demonstrate the major factors that enhance soil erosion, and for comparisons between recent records and the reference data.
- It is highly recommended to have a camera with a tripod at the reserve which can be used in the following monitoring programmes to take photos of the plots so as to show structure (soil and land) changes.
- The same methodology used in this report should be adopted when repeating the monitoring programme, as well as using the same parameters acquired when entering subsequent data.

8.1.4 General recommendations for the improvement of sustainable management in drylands

- All dryland projects with their specific objectives for sustainable management should take into consideration the local and national agenda and such priorities as poverty reduction.
- The integration of work in terms of sustainable management should be enhanced among all the active agencies and stakeholders so as to minimize duplication of work by other players.
- Training programmes carried out by many projects should be integrated to ensure that all players have the necessary capabilities and knowledge.
- A database of all the building capacity programmes for use by all the beneficiaries from these programmes should be established and shared.
- As the drylands are very fragile, the project should ensure that project failure is limited as it has devastating results on the drylands and its users.
- The use of local knowledge is very important and it should be gathered from specific surveys in order to identify this specific knowledge.
- Tools from the business world should be used to ensure that income-generating activities in the drylands are financially sustainable.
- Collaboration between all the drylands projects revealed that one joint marketing scheme to market all the commercial products in the drylands could be established.

- For each dryland site, a database should be established to note scientific information, dryland challenges, initiatives for solutions, and the challenges that face the implementation of these solutions.

9. National seminars

1. A seminar on water conservation and irrigation techniques for terraced gardens was held specifically for farmers from the district (as mentioned in section 5.2.1). This workshop took place on 12th September 2005.

2. A national seminar on dryland conservation issues took place on 3rd December 2006 at the Dana BR Centre in Dana Village. The seminar was opened by the Governor of Boseira district and by the Director General of the Royal Society for the Conservation of Nature. Thirty participants attended from local government, local communities, stakeholders, local specialists in agriculture and drylands, and others.

Through lectures, the national seminar focused on the following subjects:

- Rangeland uses and assessments in drylands: Case study of the rangeland study in Mojeb Nature Reserve.
  Presented by:
  Prof. Mahfouz Abu-Zanat
  Specialization: Range Management
  Department of Animal Production
  The Faculty of Agriculture
  Jordan University

- Best uses of medicinal and aromatics plants in drylands: Case study from Mojeb Nature Reserve.
  Presented by:
  Prof. Tallal Abu Rjea'a
  The Faculty of Pharmacy
  Jordan University

- Socio-economic studies of marginal drylands: case study from Feynan Area at Dana Biosphere Reserve.
  Presented by:
  Mr Majdy Salama
  Environmental and Socio-economic consultant

- Integrated management in the world's marginal drylands: Case study from the Sustainable Management of Marginal Drylands (SUMAMAD) project.
  Presented by:
  Mohammed Al-Qawaba'a
  Dana Biosphere Reserve Manager
  The Royal Society for the Conservation of Nature

10. Research institution and team composition

10.1 Research institution

The Royal Society for the Conservation of Nature
Dana Biosphere Reserve
P.O Box 6354
11183 Amman, Jordan
Email: adminrscn@rscn.org.jo

10.2 Team composition

Team leader: Mohammad Al-Qawabah /Dana BR Manager

Team members

Ma'an Smadi, the Head of Reserve section, RSCN
Mohammad Tabashat – Ecologist/Dana BR
Hatem Taifone – Plant researcher/research section, RSCN.
Ghazi Al-Rofa'a – Dana BR community liaison officer, RSCN.
Amer Al-Rofa'a – Dana BR patrolling unit head, RSCN.
Hawrrwn Al-Khawaldeh – Dana BR socio-economist, project head.

Lal Sohanra Biosphere Reserve and Cholistan Desert

6

Pakistan

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1. Main dryland challenges at the project site

The Lal-Sohanra Biosphere Reserve project site (Figure 1) in Pakistan is located between longitude 71° and 73° East and latitudes 28° and 30° North and about 32 kilometers from Bahawalpur City. The major part of the site is made up of desert drylands that are entirely dependent on rainfall. The main problems encountered in the project area are as follows:

- *Water scarcity for drinking and irrigation*: the primary source of good quality water is rainfall. Rainwater is collected in the natural depressions or in small excavated ponds. These ponds supply water for only three to four months and after this period the population, along with their livestock, migrate towards canal and river areas where they remain there until the following rainfall season.
- *Degraded rangelands*: the rangelands are state property; the state collects very nominal charges for livestock grazing. However, the ranges are poorly maintained. As a result, these ranges have become very severely degraded due to the uncontrolled grazing system in place and a greater livestock population than the carrying capacity allows.
- *Lack of communication*: the network of roads and telephone facilities are very rare. For the most part, tractors and camels are used to travel in the area.
- *Lack of health facilities*: there is only one health unit in the area to care for more than four thousand people. Similarly, there is only one livestock dispensary for more than twenty five thousand livestock.
- *Lack of education facilities*: the literacy rate in the area is less than 5 percent due to the absence of schools.
- *Lack of a marketing system*: there is no proper marketing system existing in the area for the sale and purchase of livestock and other necessary commodities.
- *Absence of industry related to livestock products*: e.g. milk, meat, hides, leather, wool, fur etc.
- *Lack of income sources*: other than from livestock rearing; no diversification of alternative sources of revenue.

2. Environmental characteristics of the study site

2.1 Climate

The climate of the area is an arid subtropical, continental type characterized by low and sporadic rainfall, high temperature, low relative humidity, a high rate of evaporation and strong summer winds. The study area is one of the driest and hottest areas in Pakistan. The mean annual temperature of the area is 27.5°C, whereas the mean summer temperature is 35.5°C, and the winter temperature is 18.0°C. The average maximum summer temperature goes up to 46°C and the average minimum winter temperature can fall as low as 7°C. June is the hottest month when the daily maximum temperature normally exceeds 45°C and sometimes even 50°C. The daily maximum temperature comes down in July because of the monsoon rainy season. There is always an abrupt fall in temperature during the night. Most of the rainfall in the area during the monsoon season is received in the months of July, August and September. The annual rainfall varies between 100 and 250 mm. About half of the total rainfall comes under the threshold category, while the remainder does not create any runoff. However, on the whole the rainfall creates a favourable environment for the growth of vegetation.

2.2 Geomorphology

Geomorphologically the area presents a quite complex pattern of alluvial and aeolian deposition as a result of (a) wind resorting of the sediments into various forms of sand ridges (b) resorting and further deposition in spill channels (c) deposition of sediments clayey flats (d) wind resorting and dune formation.

2.3 Soil characteristics

The soils are moderately calcareous. The pre-dominant part consists of sandy deposits whereas clayey, loamy and silty soils are also present. The soils developed from alluvial material are brown/dark brown to yellowish brown in colour. Most of them are homogenized to a depth ranging from 30 to 150 cm with a weak coarse or medium sub-angular blocky structure. The soils are presently barren due to the lack of water and have severe salinity and sodicity problems. The soils formed from aeolian material are brighter in colour and very deeply homogenized. The main soil types in the project site are dune land, sandy, loamy and clayey.

2.3.1 Dune land

The sand dunes have undulating to rolling topography. These are very excessively drained, coarse textured and structureless with pH ranging between 8.0 and 8.2. The extent of sand dunes in the area is about 40 percent.

2.3.2 Sandy soil

These soils are nearly level to gently sloping. The soils are deep to very deep, excessively drained, calcareous, and coarse textured consisting of fine sands as well as loamy sands, developed in completely wind resorted fine sand. The soils have brown/dark brown to yellowish brown, fine sand to loamy sands, single grain to massive, moderately calcareous top soil underlain by yellowish brown, fine sand to loamy sand, massive breaking in to single grain, moderately to strongly calcareous sub-soil. The pH ranges from 8.0 to 8.5. The total extent of these soils in the project area is 33 percent.

2.3.3 Loamy soil

These soils are level to nearly level with hummocks of fine sand on the surface. The soils are moderately deep, somewhat excessively drained to well drained, calcar-

Figure 1. Marginal drylands of Lal Sohanra Biosphere Reserve Pakistan.

eous, moderately coarse textured to medium textured consisting of sandy loams, loams and silt loams, developed in the mixed calcareous alluvium derived from the Himalayas and deposited by the abandoned Hakra river as well as Sutluj rivers containing some admixture of local alluvium. The soils have brown/dark brown to yellowish brown, sandy loam to silt loam, massive, moderately calcareous top soils underlain by a brown to yellowish brown, sandy loam/loam to silt loam, weak coarse sub-angular blocky, moderately to strongly calcareous B horizon. The pH ranges from 8.0 to 8.5. The percentage area with these soils is equal to 11 percent of the project site.

2.3.4 Clayey soil

These soils are mostly flat with poor vegetation. The soils are shallow to moderately deep, poorly drained, calcareous, saline-sodic, moderately fine textured to fine textured consisting of clay loam to silty clays, developed in mixed calcareous alluvium derived from Himalayas and deposited by the abandoned Hakra as well as Sutluj rivers. The soils have brown to yellowish browns, moderately to strongly calcareous, saline-sodic, moderately fine to fine textured, massive to weak thin platy A horizon underlain by a brown to yellowish brown, saline-sodic, clay loam to silty clay, weak coarse sub-angular blocky B horizon. The pH ranges from 8.6 to 10.0. These soils make up about 16 percent of the project site.

2.4 Vegetation

The major vegetation in the project area is typical of arid tract and consists of xerophytic species. Vegetation is dwarf and sparse. The great changes in the composition of natural vegetation have been caused because of overgrazing by livestock and the cutting of woody species for fuel. The main vegetation species existing in the area are: *Lasiurus sindicus, Prosopis specigera, Crotolaria burhia, Eleusine compressa, Aristida depressa, Aerua jawanica, Panicum antidotale, Cymbopogan jawarancusa, Cenchrus ciliarus, Capparis dicidua, Salsola foetida, Sueda fruticosa, Haloxylon recurvum, Haloxylon salicornicum, Alhagai camelorum, Dipteregium galcum, Tamarix articulata, Cocohorus diprssus, Calotropis gigantia* and *Tribulus terrestris*.

Figure 2. Cholistan Desert.

3. Socio-economic characteristics of the study site

3.1 Ethnic composition of the local population

The human population residing in the project area consists of many different tribes with different characteristics, languages and customs. These tribes shifted centuries ago to these drylands from different parts of Indo-Pak. The main tribes that have settled in the project area include: Bohar, Shaikh, Larh, Kotwal, Baloach, Peryar, Deh, Jakher, Panwar, Bhatti, Maher, Behey, Langah, Dindar, Muhal, Tavri, Dad potrey, Kiallay, Muchal, Lodheray, Saran, Jun, Beein and Phularwan.

3.2 Demographic data

The total human population of the project sites is nearly 4,175 persons consisting of about 420 families of different tribes with an average family size of ten members. The livestock population in the area is about 25,000 consisting of various species i.e. sheep, goats, cattle, camels and donkeys. The livestock population in the project site is six times more than the human population. The average literacy rate in the area is below 5 percent. Most people have not received an education and those who are literate have a very low level of education. The reasons behind the low and lesser education levels in the area are due to the absence of schools and teachers as well as the migratory habits of the people who, together with their livestock, go in search of water and fodder. The medical facilities available to the population and the livestock are almost nil. There is only one health unit in the area for more than four thousand people and similarly one veterinary dispensary for more than 25,000 livestock. The water requirement for human and livestock consumption is more than 200 million litres per year.

3.3 Main sources of income

The people in this area have resided here for many centuries and their principal livelihood is based on livestock rearing consisting of sheep, goats, cattle and camels. The main source of livestock fodder is grazing on the state land. The herders pay a reasonable price for their animals to graze on an annual basis; this charge is called *teni*. The lands are not cultivated due to the absence of water for irrigation. The groundwater is generally very saline therefore agriculture is not practiced as a main source of income. The rainfall is scarce, and due to its irregular distribution is insufficient for the cultivation of crops. Each person in the area possesses on average six animals that include cattle, sheep, goats and camels. The average market price for six animals consisting of sheep, goat, cattle, camels and donkeys is about fifty thousand Pakistani rupees or about eight hundred US dollars.

Demographic variables	Quantification
Human population	4,175
Livestock population	25,955
Education schools	2
Human health centre	1
Livestock health unit	1
Drinking water requirement per year	200 million litre
Literacy rate	5 percent

Table 1. Demographic data from the project site.

There are four major economic activities in these drylands: livestock rearing, manual labour, production of local handicrafts, and agricultural farming on the periphery of the desert. About 70 percent depend on livestock rearing, 20 percent earn their income from different forms of labour, about 8 percent perform agricultural activities, and about 2 percent earn their living by making handicrafts.

4. Conservation of natural resources

4.1 Water resources management

Water is fundamental for human, animal, bird and plant life in fact all living things. Therefore water conservation is vital for other types of activities and the conservation of resources such as land, plants, environment and ecology. Water availability is essential for the irrigation of crops and plants that are beneficial to humans, animals, and birds, and to protect the land against natural vagaries or anthropogenic agents of land degradation. There are no canals, rivers or any other sources of freshwater in the project area except rainwater. Rainfall is low and cannot alone support the plantation of trees, shrubs, bushes, grasses, herbs and crops. Therefore, there are three options to develop water resources in the project site i.e. through rainwater harvesting. These are: 1) rainwater harvesting, 2) the conjunctive use of rainwater and saline water, and 3) the use of saline water for salt-tolerant plants. About 16 percent area of the project site consists of fine impervious clayey soils, the best catchment for collecting runoff in the ponds to be used for the consumption of human, livestock, wildlife and birds, and for plant irrigation to conserve the ecosystem. Therefore, rainwater harvesting should receive maximum attention. The groundwater is saline therefore the combined use of rainwater and saline water needs to be introduced to solve the water scarcity problem. Furthermore, saline water can be used for irrigation of salt-tolerant plant species so as to develop more vegetative cover on the land.

4.2 Sand dune afforestation

Sand dune stabilization with perennial vegetation cover will halt sand migration towards irrigated fertile lands and thus prevent their abandonment; it will also produce timber, fuel wood and forage for livestock. This will generate various economic sources. Furthermore, the environment will be in a comfortable position insofar as this will rehabilitate degraded lands for sustainable use. The most durable and economical approach to control the migration of the sand dunes is by establishing vegetation cover. This can be achieved either through slow natural succession or by revegetation and afforestation with drought resistant species of trees, grasses and shrubs. Prior to sand dune stabilization by vegetation, the shifting sand needs to be fixed in order to create a favourable environment for plant growth, and thus ensure its survival in the desert climate. Sand dune fixation is designed to prevent the movement of sand for the length of time it takes for either natural or planted vegetation to become established.

Trees provide several goods broadly classified as major and minor products, and which serve as raw materials for many industries. Trees provide numerous services such as environmental and ecological stability. Wood is a versatile product upon which many industries rely, for example, railways, housing, furniture, pulp and paper, rayon, fibre, plywood, carved wooden articles, wooden utensils, and safety matches. Wood is the main source of energy for cooking food, particularly in rural areas. Wood and grasses form the basic raw material for paper manufacture, a vital commodity in terms of literacy and public education. The villager's mainstay is agriculture and their primary needs are food, fuel, shelter, fodder and fertilizer. All these commodities are products of a stable land system in which the protective role of trees play a vital role. If marginal drylands are utilized for growing trees, grasses and shrubs of economical importance then it will increase the overall national production of timber, livestock, milk, and wool products.

The project site has poor to moderate vegetation cover, therefore wind erosion is severe and good fertile rangelands and adjoining irrigated areas are threatened. If sand dunes are fixed and stabilized by growing valuable and economical trees or shrubs then the otherwise barren dune land will generate sources of income in the form of timber, milk, meat, wool and hides etc. instead of compounding the wind erosion problem.

4.3 Arid horticulture

Water for drinking purposes and for establishing orchards can be managed with the use of technical skills employing a rainwater harvesting system. About 16 percent of the project site consists of dense clayey soils devoid of vegetation, or having poor vegetation canopy. The area is mostly flat, impervious, and saline-sodic, and has a pH of more than 9.0. Runoff depends on the quantity of precipitation and soil characteristics. This area is the best catchment for rainwater harvesting and storage in ponds; the area is managed for enhanced runoff and efficient water collection. The quantity of rainwater collected in the ponds can be utilized for the irrigation of orchards. Groundwater has an EC below 5.0 d Sm^{-1} so it can be safely used on dune land and deep sandy soils for the irrigation of salt-tolerant fruit trees in conjunction with rainwater as well as independently because salts from saline water will leach down rapidly from the root zone of plants because of the excessive drainage feature of sandy soil. Occasionally, in excessively drained soils, heavy rains also flush salts beyond the root zone. Further amendments can also be applied together with saline water to neutralize the adverse affects of salinity. Date and *Zizyphus* are salt-tolerant and drought-resistant fruit trees which can be successfully planted in the project area in the form of orchards to develop an additional source of food and income, as well as for human food security.

4.4 Evaporation losses control from water ponds

Evaporation losses from ponds because of exposed surfaces, and the harsh climatic conditions in the project site, is a significant problem resulting in water losses of between 35–40% of the total quantity stored in the ponds. The evaporation losses can be reduced by increasing the water storage and the depth of the pond/reservoir, and by establishing windbreaks around the water body as well as by covering the exposed water surface with suitable materials. Water is a very expensive commodity in the project site compared to milk because without water, the survival of humans, livestock, wildlife, birds, and vegetation would be impossible. Life is very precious as it maintains beauty on Earth therefore efforts should be made to ensure its safety and welfare by providing the maximum amount of water from any available source in the desert environment.

4.5 Saline agriculture

Water scarcity is the main obstacle to the use of marginal drylands for beneficial purposes. Saline water can be used to grow salt-tolerant trees and fodder grasses on sand dunes with no adverse effects due to the rapid leaching of salts beyond the root zone, and the flushing of salts from the root zone by rains. Although the underground water is saline and not suitable for human consumption, it can be used for saline agriculture to grow salt-tolerant trees, vegetables, crops and fodder grasses on non-saline-non-sodic coarse textured sandy soils due to the rapid leaching of salts beyond the root zone. Furthermore, the dense saline-sodic clayey soils can also be used for growing palatable grasses, which are very salt-tolerant and capable of surviving on poor soils. The sandy soils can be brought under saline agriculture by using underground saline water. The salts accumulated as a result of irrigation by saline water are flushed to very deep layers during the rainy season by rainwater percolation because of the excessively well-drained nature of the sandy soils. Moreover, the adverse effects of saline water on the physical properties of soils can be neutralized by applying the required amount of gypsum, farmyard manure, and inorganic fertilizers.

The purpose of saline water management is to improve water availability for trees, grasses, fodder, crops, and vegetables when considering the quality of water and the water requirement.

The most appropriate method of irrigation should be selected such that there is neither a deficit nor an excess of soil water. However, excess water may be purposely applied in order to maintain the salt balance that may occur due to leaching. The salinity regime of a plant depends upon a number of factors such as the stage of growth when salinization occurs, the rate of salinization, the length and time of exposure to salinity, the periods of low salinity levels, and salinity distribution with depth in the profile. In any field condition it is difficult to control these factors and the variability among these factors may be responsible for wide variations in the salinity tolerance data for various locations. The management practices which modify one or more of these factors in favour of plant growth will help in the use of saline water for irrigation.

4.6 Rangeland management

The vegetation of the desert range consists of very sparse and scattered growth of xerophytic perennials and ephemerals; small shrubs and wiry grasses provide forage intermittently, depending on the erratic rainfall. The range is considered to be in excellent condition when the present plant composition is as near to climax as possible, whilst it is considered to be poor when markedly different from the local climax type. Overgrazing is the greatest cause of range deterioration in the project area. Due to overgrazing, the palatable species regress rapidly and are replaced by annuals; the soil becomes progressively denuded, erosion effects are intensified, soil structure is degraded, and organic matter is reduced. The long-term effect of overgrazing is therefore degradation of the range. But even on a short term basis, excessive grazing reduces productivity, especially under conditions of limited moisture supply. The effects of heavy grazing are mainly detrimental to the valuable species; the animals graze heavily on the most palatable plants thereby depleting their food reserves and causing the loss of their vitality and ability to produce seeds hence they are rapidly replaced by the less palatable plants. As a result, the carrying capacity of the range is reduced. Rangeland can be managed efficiently with the following practices:

1. Reseeding of native grasses.
2. Animal grazing as per carrying capacity of the area to check overgrazing.
3. Maintaining animal growth and reproduction rate as much as the environment allows.
4. Reserving sizable grazing areas which could be utilized during drought periods.
5. Establishing fodder reserves to meet droughts.
6. Supplementing with concentrate feed under extreme circumstances.

4.7 Introduction of a silvipasture system

To overcome the problem of fodder in the project site under a stable environmental system, silviculture and pasture development is the best and most ideally suited system. The trees and grasses to be included in the system should be drought-resistant, salt-tolerant, palatable, fast growing and capable of producing more biomass, as well as be suited to economical benefits. More than 50% area of the project site is covered by sand dunes, sandy soils and hummocks with gentle to undulating topography. These sandy areas have poor vegetation, therefore wind erosion is significantly active. If these areas are brought under silviculture and pasture development by irrigation with saline ground water then it will increase overall production in timber, livestock, milk and wool products.

5. Practices implemented for soil and water conservation

5.1 Rainwater harvesting traditional practices

5.1.1 Tobas (small ponds)

These are excavated in the project area near grazing land or in the village to collect rainwater for human and livestock consumption. Tobas are excavated by each tribe in their own grazing area occupied by their ancestors for centuries. There is also a communal living space in the form of a village consisting of many tribes where there is a joint effort to excavate tobas. Spades are used to dig up the earth which is then piled the length of the side such that three sides are kept open to allow rainwater to enter from these directions. The tobas are not excavated under planned scientific surveys i.e. with the use of topo and contour surveys. However, the lowest point is selected in the catchment where more rainwater can be collected through runoff, and therefore will contain water for longer periods. Tobas are positioned through experience. Its depth is kept to a maximum of 2 m without proper levelling of the bed. There is no planned regular channel or inlets for the entrance of rainwater into the toba. Rainwater can enter the toba in a natural way from any of the three open directions, though unfortunately the slopes are not properly maintained as they ensure stability. The size of the tobas is generally small with water storage capacity of less than 1,500m^3. Its length varies between 30–60 m, its width ranges between 20–40 m, and its depth between 1–2 m. No seepage and evaporation loss control measures are adopted. The rainwater collected in these tobas is stored up to a maximum of four months. Tobas water is used by the tribe himself, outsiders are not allowed to take water for drinking or other uses. However, in the case where tobas are constructed through joint efforts, the whole community can use this water.

5.1.2 Dug wells

The open wells have been constructed using pucca bricks where groundwater is drinkable. The quality of groundwater for well construction is judged by taste and not by proper scientific analysis. Water from the wells is drawn by big leather buckets attached with rope made from goat hairs or leather strips and pulled by camel. The large bucket filled with water is carried by two to three men. The well is the property of the tribe who constructed it. The well water is used when rainwater in the toba dries out. However, the rainwater collected in the tobas is preferred for drinking. In an area where pucca bricks cannot easily be used due to the harsh and very remote conditions, local lime is plastered onto the walls to consolidate the well and prevent the well from collapsing.

5.2 Rangelands

For centuries each tribe has occupied its own area in the project site for livestock grazing. The area belongs to the state and the government authorities only collect nominal charges annually for grazing per livestock animal, locally called *teni*. No other tribe can use the grazing land of the occupied tribe without prior permission. However, grazing lands can be shared by mutual consent. There are two ways of grazing livestock in the area: 1) each tribe has their own grazing land and water point away from the village where they graze their livestock for as long as there is water and grass. When the water or grasses are exhausted they migrate to the village where a communal water point and grazing land can be used for livestock grazing; 2) near the village each tribe occupies their own range. These ranges are not maintained by a controlled grazing system; a free grazing system has prevailed here for centuries. No seeding is carried out in the ranges. In addition, the livestock is not kept as per carrying capacity of the ranges; there is no restriction on grazing during the vegetation sprouting season. As a result, the ranges are overgrazed and degraded.

5.3 Modern technologies for soil conservation

5.3.1 Transformation of barren dunes in to forest land

The majority of the dune land in the project site has less than 20% vegetation cover. As a result, wind erosion is active and sand encroaches on good lands. The sand dunes are stabilized by providing greater vegetation cover through the introduction of fast growing trees that can generate income in the form of forest and fruit plants such that an income can be derived from timber and fruits from these wastelands. PCRWR has converted more than 50 hectares of dune land, which previously had a vegetation cover of less than 15%, into good forest land with more than 80% vegetation cover. The main tree species grown in the vicinity of Dingarh – Lal Sohanra include *Acacia, Tamarix, Zizyphus, Prosopis, Parkinsonia*, and *Ampliceps*.

5.3.2 Development of grassland

The Pakistan Council of Research in Water Resources (PCRWR) has developed grasslands in an area covering more than 35 hectares in Dingarh through the use of saline groundwater irrigation. Although the groundwater is saline and not suitable for human consumption, it is being used successfully to grow salt-tolerant fodder grasses on coarse textured sandy soils thanks to the rapid leaching of salts beyond the root zone. The salts accumulated due to irrigation by saline water are flushed to deeper layers during the rainy season by rainwater percolation because of the excessively well-drained nature of the sandy soils. Furthermore, the adverse effects of saline water on the physical properties of soils are neutralized by applying the required amount of gypsum, farmyard manure and inorganic fertilizers. The grasses namely *Napier bajra, Panicum, Gyna, Sporobolus cenchrus*, and *Lasiurus* have been grown using saline water irrigation with a salt concentration of more than 4,000 ppm. The grasses proved to be excellent vegetation cover for the sandy soils.

5.3.3 Introduction of new valuable plants

Jojoba is a valuable ornamental and oil-producing plant. The high wax produced by Jojoba seed is a good substitute to sperm whale oil. Jojoba plant can reach a height of 61–183 cm but it may grow up to 300 cm or more in stature and offers a thick vegetative cover in the desert. The plant has a natural life span of between 100–200 years. PCRWR have grown the Jojoba plants at Dingarh Station by combining rainwater and saline groundwater. The plants reached an average height of 183 cm with an average canopy cover of about 244 cm. The majority of the plants bore fruit.

5.3.4 Range development

Various species of grasses, trees and bushes (*Atriplexes*) have been introduced at the Desert Field Research Station in the project area using saline groundwater. These salt-tolerant plants are palatable to the livestock. The bushes are the best sand dune stabilizers due to their very good and solid stature. These bushes provide green forage during dry periods especially when other vegetation is dry.

5.3.5 Agro-forestry in the desert and the conjunctive use of fresh and saline water

More than 50 hectares of dune land has been converted by PCRWR into agro-forestry lands in the project area in order to introduce income-generating activities to the marginal drylands and thus contribute to the national economy. The fodder and oil seed crops are grown alongside forest trees. The most important crops are cluster beans, mustard and barley whereas the tree species include *Acacia* and *Zizyphus*, which are usable as timber and for fruit.

5.3.6 Desertification control

Due to wind erosion, the desertification of drylands at the project site is a major problem. Wind erosion is mainly attributed to poor vegetation cover as a result of overgrazing and the removal of woody vegetation for fuel and timber in addition to the poor physical properties of sandy soils. The PCRWR has stabilized more than 50 hectares of the mobile sandy area with poor vegetation cover at Dingarh in the Lal Sohanra project area by increasing vegetation cover using rainwater and saline groundwater. The site was fenced off to avoid grazing and woodcutting. Prior to plantation, the mobile sandy area was fixed by erecting micro-barrier fences made from dead plant material and placed in a checkerboard pattern. Prior to fencing and the plantation of the study site, the natural vegetation canopy was measured to make comparisons over certain years. The canopy cover before fencing and plantation was between 10 and 32%. After 5 years, it increased to 75–98%. Today, the area is free from wind erosion and presents a good example of desertification control.

5.4 Modern rainwater harvesting technology

5.4.1 Identification and selection of catchments

The catchments are identified and selected after proper contour surveys were carried out as per scientific procedure. Impervious clayey soils exist over an estimated area of more than 0.4 million hectares (1.0 million acres). These areas are mostly level without vegetation or with poor vegetation. The clayey soils in these areas are shallow to moderately deep, poorly drained, calcareous and saline-sodic. These clayey areas are naturally good catchments and need some alteration for producing more runoff through a network of micro- and macro-ditches, and to obtain prompt runoff in response even to low rainfall. These clayey soils start to generate runoff after infiltration of about 9 mm of continuous rainfall. However, if rainfall occurs within less than one or two-day intervals then runoff can occur after less rainwater absorption. These clayey areas are spread throughout the desert at various locations in the Cholistan Desert and are the best catchments for rainwater harvesting and pond construction.

A suitable reservoir catchment for rainwater harvesting with poor water intake characteristics is selected following an appropriate contour and profile survey. Preference is given to areas without vegetation or with very little vegetation so as to generate a more natural runoff flow towards the storage areas. The small sand hummocks and sand ridges within the catchment are removed or stabilized. The infiltration rate in the catchments should be measured to identify the best appropriate site, which is more impervious or poorly drained. If impervious soils are covered with dense vegetation then it should be removed to increase runoff. Furthermore, the lowest points in the catchment should be interlinked through a network of ditches or bunds leading towards the pond or reservoir. The other catchment development techniques e.g. sand stabilization, soil compaction, and surface smoothing should also be followed. As a result of such efforts, efficient catchments can be developed from where the required quantity of runoff can be collected in the storage areas.

5.4.2 Site selection for reservoirs

With knowledge gleaned from a contour survey, an appropriate site for the reservoir in the catchment should be selected at the lowest point so as to collect maximum rainwater within the shortest possible time following rainfall. The length of time that rainwater remains in the catchment as well as past knowledge of the catchment from local people residing in the area should also be considered in the selection of the reservoir site. Ideally, the reservoir that provides the water for human consumption should be situated close to the settlement and away from frequent livestock movement to prevent accidental mixing of dung with the runoff and the stored rainwater. The reservoir site should be selected where there are no sand movements under the action of wind erosion due to mobile sand dunes. The reservoir site that provides water to livestock should be close to the range-land or grazing land as much as possible so as to minimize the distance needed to travel and thus reduce their drinking water requirements.

5.4.3 Design and size of reservoirs

The optimum construction size of the reservoir or pond for the Cholistan Desert has been set by the Pakistan Council of Research in Water Resources after conducting experiments over many years and has a storage capacity of 15,000 m^3 for a catchment of 20 to 50 hectares with runoff ranging between 20 and 60 mm annually. The length of the reservoir surface is 60 meters while the length of the reservoir bed measures 40 meters. The reservoir has the same width measurements as its length. The reservoir has a depth of 6 meters with a side slope of 1:2. The reservoir is connected with the catchment through a main channel measuring 16 meters in length, and rainwater falls into the pond through steps on the slope so as to avoid possible damage to the reservoir structure due to water erosion. The network of ditches in the catchment has been constructed to de-load silt material before the rainwater runoff enters the reservoir and thus minimize siltation. The purpose of the ditches is to quickly collect runoff during and after the rains. The main channel and steps in the reservoir should be constructed using pucca material.

5.4.4 Seepage control

The seepage losses from the reservoir have been reduced at low cost by ensuring that the reservoir bed lies on the dense impervious clay layer, and by spreading good quality polyethylene sheets on the bed of the reservoir covered with a 15 cm thick compacted layer of dense clay.

5.4.5 Evaporation control

The evaporation losses from the reservoirs were reduced by minmizing the surface area of the reservoir while increasing its depth, and by establishing windbreaks around the reservoir by growing trees in a multi-storey form, and erecting high earthen bunds around the reservoir to minimize the direct contact of hot winds with the water in the reservoir which causes evaporation.

5.4.6 Water sources developed by PCRWR

The research results of rainwater harvesting and the storage experiments carried out at Dingarh Field Research Station in the Cholistan Desert for the last fifteen years have been multiplied and conducted throughout the desert spread over about 26,000 km^2. The Pakistan Council of Research in Water Resources conducted research on a rainwater harvesting system and identified the potential runoff from rainfall ranging between 167 and 672 million m^3 annually in average rainy years. The potential average annual runoff of 18 years is 286 million m^3. The Pakistan Council of Research in Water Resources has constructed 92 reservoirs each with a storage capacity of 15,000 m^3 to collect 1.38 million m^3 of rainwater after proper scientific surveys. To harvest and collect the average runoff from 442 million hectares in Cholistan 21,000 reservoirs each with a storage capacity of 15,000 m^3 needs to be constructed. Twenty turbine tubewells and two Reverse Osmosis treatment plants have been installed to provide more than 6.5 million m^3 of good quality water in addition to rainwater. Drinking water is now available in the desert throughout the year. As a result of this water source installation, the huge migrations of people and livestock that occurred because of the scarcity of drinking water has now ceased, and annual losses of 6 billion rupees due to a reduction in livestock production through mortality, disease, a fall in meat and milk production as well as damage to crops in the irrigated areas along the canal have been saved. Furthermore, the microclimate around the reservoirs has also improved conditions for wildlife. Now birds and other wildlife are frequently seen around the reservoirs, even now new plant species can be identified in the vicinity of the water reservoirs.

6. Income-generating activities

6.1 Commercial livestock farming

The current livestock production in the Cholistan is less than its actual potential due to the unavailability of good quality drinking water for the local population and their livestock, as well as the fact that the pasture lands are not managed in any way. The sole source of good quality water in the Cholistan Desert comes from rainfall, which varies between 100 and 250 mm on average but can in some years exceed this. Water from rainfall is collected on ill-adapted sites and in a way that does not take into account scientific measurements such as the physical and chemical properties of soil, topography, contour of the catchment, evaporation rate and so on. As a result, these ponds have little storage capacity and therefore hold minimum quantities of water; they also suffer from considerable losses in the form of evaporation, seepage and so on. Furthermore, the water in the ponds is left unfiltered with the result that suspended particles of silt and clay remain in the water rendering it unfit for human and livestock consumption, which inevitably causes health problems. The water in the ponds last for a maximum of three to four months, and saline groundwater is used for human and livestock consumption for as long as fodder is available in the Cholistan Desert. Drinking saline groundwater from the dug wells weaken the livestock, and the unavailability of the necessary quantity and quality of drinking water means that the livestock graze on more vegetation and as a result the carrying capacity of the ranges declines.

All the above mentioned factors reduce the potential of livestock production; there is a great potential for livestock farming if good quality drinking water and fodder is made available. So far, 8 million m^3 of drinking water for human and livestock consumption has been developed by PCRWR, which satisfy the needs of 0.1 million people and 2 million livestock. Livestock production in the project area is the biggest economic activity and the mainstay of the Cholistan inhabitants. Livestock production in Cholistan is mainly based on grazing herds of cattle, sheep, goats and camels, which are owned by families and collec-

Figure 3. Fish pond at Dingarh in Lal Sohanra Biosphere Reserve, Pakistan. *(top)*

Figure 4, 5. Fish production from saline fish farming in Lal Sohanra Biosphere Reserve. *(bottom)* tively. Actual production could be enhanced many fold by improving feeding practices under drought conditions i.e. by increasing vegetative growth in the area, which could be converted into hay and silage bundles. Mineral supplements and the application of other management practices would also improve overall conditions for the population.

6.2 Saline fish farming

Due to the rapidly increasing population, demand for food is increasing daily. It therefore becomes imperative to use marginal, unexploited land and water resources to meet these food requirements. Fish farming can play a vital role in this respect when agriculture and livestock production cannot increase at the desired rate. The water resources in the drylands of Pakistan have not been exploited or properly managed for sustainable production. The main sources of water in the vicinity of the drylands of Lal Sohanra Biosphere Reserve are rainwater and groundwater. Groundwater is mostly saline and has not been exploited yet the saline water can be used for fish production to generate an alternative livelihood. The concept of saline fish farming seems to be the more appropriate way to utilize waste land and water resources in the drylands. The study has been carried out in the drylands of Lal Sohanra Biosphere Reserve at four locations i.e. Dingarh, Malkana, Jaisa and Thandi Khui, and with the following objectives:

- To explore alternative income-generating sources for farmers of dryland areas.
- To study the potential for additional sources of meat to meet the increasing food demand of the rising population by utilizing saline water and dryland resources.
- To demonstrate to the dryland community that better utilization of the existing land and water resources can alleviate poverty.

Figure 6. A view of egg plant crops grown in the drylands of Lal Sohanra Biosphere Reserve. *(top)*
Figure 7. A view of musk melon. *(bottom)*

Groundwater with different salinity levels was pumped through tubewells at all the above cited sites. The groundwater of all four sites varied between slightly saline to highly saline. The fish species used for the experiment in the polyculture were: Silver carp, Grass carp, Rahu, Moori and Gulfam, and produced good results. Another study involving saline fish farming, carried out by PCRWR in the first instance, was later carried out by the population and also produced encouraging results.

6.3 Introduction of ostrich farming

Ostrich farming in the marginal drylands of the Lal Sohanra project site could also meet the demands for meat in the country as well as become a good source of income. The climate and land features are quite adequate for ostrich farming. The ostrich has a remarkable tolerance to heat and can withstand air temperatures of up to 56ºC without undue stress. They also rarely seek shade as most desert animals regularly do. There are commercial ostrich farms operating in many countries such as Argentina, Australia, Egypt, New Zealand, and USA. Today, ostrich farms are considered to be among the most profitable agricultural projects. They are often referred to as 'the farms of the future' because of the large variety of possible products and hence their high project potential i.e. meat, hide and feathers.

6.4 Collection and utilization of economic plants

Since time immemorial, desert plants have supplied many of local inhabitants' needs. Food and spices, fibre, medicines and drugs, and shelter materials are obtained from a large variety of desert plants. In the Cholistan drylands, the tender leaves of many plant species serve as vegetables for local people. Pods of *Laptadenia sparticum* (*khip*) are used as a food source, after some processing their branches provide fibre. Once processed, *Haloxylon recurvum* (khar) is used by local people as soap for washing clothes. Fruits of desert plants are also used by the local inhabitants as food. Fruit of *Capparis decidua* (*karir*) is used for pickle by the local people. Many desert plants have biochemical constituents that have a therapeutic value or serve as narcotic drugs or stimulants. In addition to the above, dyes, gums and fuel have also been obtained from desert plants, in fact all valuable plants can be commercialized but priority should be given to plants used for medicine, food, fibre, pickles and others.

6.5 Vegetable farming

The water resources in the marginal drylands of Lal Sohanra Biosphere Reserve can be developed for water consumption by the human and livestock population as well as for vegetable farming using an efficient irrigation system of rainwater harvesting and storage in appropriate ponds. The Pakistan Council of Research in Water Resources has successfully developed such ponds that hold water for the entire year in average rainfall years. Today, there is sufficient drinking water for the human and livestock populations in the Cholistan drylands. It is also estimated that about 286 million m^3 of rainwater could be harvested and stored from the marginal drylands of Cholistan Lal Sohanra Biosphere Reserve; this water could be utilized for growing vegetables. Another source of water i.e. saline groundwater could also be utilized on the deep sandy soils for vegetable farming and farm production either on its own or in conjunction with rainwater. It could potentially provide the best income and food source for the local people. The study 'Vegetable production with irrigation by saline water' was conducted to develop a model for vegetable farms. The vegetables grown were eggplant, pepper, red gourd, bottle gourd and bitter gourd. This study motivated the local farmers to multiply the results on a multi-scale level to obtain good vegetable production by utilizing local dryland resources efficiently and economically. This will increase local farmers' income and provide food security by improving protein sources for the population living in the marginal drylands; it will also help raise their social status among society.

7. Results obtained

7.1 Assessment methodology in the Lal Sohanra Biosphere Reserve

1. The climate of the project site is the arid subtropical continental type, characterized by low and sporadic rainfall, high temperature, high rate of evaporation and strong summer winds.
2. The project site consists of 59% sand dunes, 13% non-saline-non-sodic sandy soils, 4% non-saline-non-sodic loams, 8% saline-sodic sandy loams, and 16% saline-alkali clayey soils.
3. Grazing is the principal land-use of the project site. Extreme aridity, the predominantly sandy nature of soils, and the extreme lack of drinking water are the main factors inhibiting the use of the area as arable land.
4. Carrying capacity of the project site is 18,552 sheep or goats, or 3,691 cattle, or 1,856 camels.
5. The vegetation of the project site is typical of arid tract and consists of xerophytic species.
6. The problem of wind erosion in the project area is severe due to overgrazing and the removal of vegetation. The problem is very acute near dwellings, where once sand dunes were stabilized they have now been converted into actively moving sand.
7. About 25% of the area is severely affected by salinity and sodicity.
8. The problem of soil compaction is severe where soils are strongly saline-sodic and are composed of silty clay loam and silty clay.
9. The major processes of desertification in the project area are:
   – degradation of native vegetation due to overgrazing;
   – destruction of woody species for fuel;
   – wind erosion;
   – salinity and sodicity;
   – water scarcity.

7.2 Research and test out sustainable management strategies in Lal Sohanra

7.2.1 Main problems in the project area

1. Shortage of water resources.
2. Shortage of education facilities.
3. Shortage of health facilities for humans and livestock.
4. Very low literacy rate.

7.2.2 Drought impacts

1. Water scarcity.
2. Migration of human and livestock population.
3. Loss of income due to death of animals, over expenses and diseases.
4. Vegetation degradation.
5. Wind erosion.

7.2.3 Economic resources of the people

1. Livestock rearing.
2. Manual labour.
3. Agriculture.
4. Handicrafts.

7.2.4 Impact on Lal Sohanra Biosphere

1. Environment improvement.
2. Fauna and flora preservation.
3. Recreation for the population.
4. Timber availability.
5. Majority of the people replied that they received no personal benefits.

7.2.5 Proposed dryland management approaches

1. More rainwater harvesting.
2. Construction of more water storage ponds.
3. Desiltation of existing ponds.
4. Catchment development by creating ditches, bunds, vegetation clearings, and removal of sand hummocks.
5. Identification of appropriate catchments by survey.
6. There should be water pumps drawing water from ponds.

7.2.6 Identified additional income-generation sources

1. Livestock farming.
2. Saline fish farming.
3. Poultry farming.
4. Handicrafts.
5. Medicinal plants marketing.
6. Arid horticulture.

7.2.7 Constraints to the adaptation of management approaches

1. Financial.
2. Technical.
3. Technical training.

7.2.8 Saline fish farming as an alternative livelihood in Lal Sohanra

1. A large part of the soils in the project area is suitable for creating ponds for fish culture consisting of various fish species.
2. In drylands, fresh and saline groundwater resources can be utilized for fish culture.
3. In dry areas, rainwater harvesting can also play a role in fish culture.
4. The fish species suitable for use in saline waters are Silver carp, Grass carp, Catla, Rahu, Moori and Talapia.
5. Fish culture in the dry areas is appropriate using an integrated farming system in the form of livestock-cum-fish farming or agriculture-cum-fish farming or fish farming-cum-sericulture or fish farming-cum-horticulture or duck-fish farming or poultry. Fish farming or cattle-fish farming.
6. To make fish farming alone reasonably economical, there should be more than ten ponds each measuring one acre.
7. To ensure the success of the fish farming system and minimize mortality rates, a polyculture fish combination system should be adopted.
8. To achieve an optimum yield from the fish farms, artificial feed and the use of fertilizers as well as medical care is a must, in addition to natural plant feed.

7.2.9 Vegetable production in the Lal Sohanra drylands

1. The climate in the project site is very harsh especially during the summer months when blowing winds result in severe wind erosion, temperatures above 50ºC, high evaporation, high transpiration, and reduced rainfall. Due to these factors, plant growth cannot be assured and plant mortality is high requiring more water for growing summer vegetables or other crops. Moreover, climate is more suitable for growing winter vegetables or other crops.
2. Land for the cultivation of vegetables or crops should be fertile and well drained. Loamy soils are more suitable for growing vegetables.
3. The land should not be saline or saline-sodic if growing vegetables that are saline-sensitive.
4. The land should be free from high sodium concentrations, well permeable and well drained.
5. The rainwater collected in the reservoirs is best for growing all types of vegetables on non-saline and non-sodic soils having good permeability or good drainage.
6. The marginal quality groundwater can be used for growing summer and winter vegetables with the use of soil management practices.
7. Moderate to highly saline waters can also be used for growing more salt-tolerant vegetables on the excessively drained and fertile lands, and where wind erosion is not a serious problem.
8. Water management practices should be adopted when saline waters are used for irrigation i.e. adding manure, fertilizers, planting vegetables on ridges and beds etc.
9. Mulch materials should be used to conserve soil

moisture over a longer period of time. This helps to produce better vegetable crops.

10. The application of inorganic fertilizers increases seed germination and plant survival, and promotes better growth and good plant yield.

8. Recommendations and conclusions for sustainable dryland management

1. Schemes should be made to improve water supplies, reduce water losses, improve the efficient use of water, and develop new water resources.
2. Overgrazing in the study area should cease, and rotational grazing should be adopted to allow the vegetation to regrow.
3. Grasses such as *Cenchrus ciliaris* (*dhaman*) and *Lisiarus hirsutus* (*gorkha*) should be re-seeded in the study area.
4. Animal grazing should be permitted according to the carrying capacity of the area.
5. Watering points should be constructed at suitable places.
6. Fodder reserves (hay and sillage) should be established to meet the forage requirements during the dry season or drought.
7. Grazing should be prohibited during the growing season but if that's not possible then at least the number of animals should be reduced.
8. In order to control wind erosion in the area, the shifting sands should be stabilized by introducing vegetation cover either through slow natural succession or by re-vegetation.
9. The use of windbreaks should also be used to control the problem of wind erosion.
10. Modern chemical methods to stabilize the sand, which is subjected to wind erosion, should be tried.
11. The study area affected by severe salinity and sodicity should be used for salt-tolerant grasses, trees etc.
12. Windmills should be installed to facilitate pumping of drinking water from the deep wells for both human and livestock consumption.
13. Cutting of trees and woody species should be strictly prohibited.
14. Biogas should be installed to prevent the removal of valuable plant species for fuel.
15. The existing dispensaries for people and livestock should be improved by providing adequate medicines and other equipment.
16. Rainwater harvesting should be maximized through the use of economical and scientifically designed earthen ponds.
17. Appropriate management of range and grasslands should be applied.
18. The drylands should be developed by planting drought-resistant and salt-tolerant trees, fruit plants, bushes, grasses etc. using saline groundwater.
19. The indigenous cottage industry should be promoted.
20. Communication, health and educational facilities should be developed.
21. Livestock farming should be improved.
22. Saline fishery farming using saline groundwater should be promoted.
23. Poultry and local bird farming should be promoted.
24. Pickle-making from desert fruit trees should be promoted.
25. The productive use of desert medicinal plants should be promoted.
26. Plantation of local fruit trees should be increased.
27. Local handicrafts should be promoted.
28. The sand dune should be stabilized.
29. Orchards should be developed.
30. The afforestation of dune land should be promoted.
31. Range and grassland management should be applied.
32. Water conservation techniques should be employed.

33. Evaporation and seepage control in ponds should be employed.
34. Ground water recharge should be promoted.
35. A vast saline groundwater body lying unutilized in the dry areas of Pakistan could be used to produce food and be converted into income-generation sources for human beings.
36. The saline groundwater resources found on barren land should be used to promptly develop an economic source for the country.
37. Saline fish farming if adopted by the local inhabitants may improve socio-economic conditions by providing labour and employment.
38. Fish farming could potentially contribute as a major source of protein for the country and to the national economy. It could revolutionize protein food supply similar to poultry farming.
39. Select areas known to have a mild climate where crops and plants have to be cultivated or planted.
40. Fertile and well-drained soils should be selected for vegetable cultivation.
41. The loamy well-drained soils should be prepared for the cultivation of vegetable crops.
42. The barren lands cleared for cultivation should be cultivated with grasses for a period of one or two years to render the soil porous and improve permeability before vegetable cultivation.
43. Excessively percolated soil should not be used for sowing vegetable crops where irrigation water is of good quality; conversely, where irrigation water is saline, excessively drained soils are more suitable for growing vegetable crops.
44. To improve soil fertility, organic soil matter should be increased by adding manure and nutrients. Inorganic fertilizers should also be used to provide nutrients to vegetable plants.
45. The land should be well prepared before cultivation of vegetable crops or plants as per their requirements, and plantation or cultivation procedures.
46. Wherever possible, the irrigation water should be of good quality whether it comes from the river, canal, groundwater, rainwater collected in the reservoirs or conserved in the soil through different operations or mulches.
47. If good quality water is not available then marginal quality water should be used on well-drained soils.
48. If marginal water is also not available, then moderately saline water should be used for growing vegetable crops or plants on excessively drained soils in which case, salt-tolerant plants or vegetables should be selected.
49. If moderately saline water is not available then highly saline water should be used on deep very excessively-drained soils in which case, highly salt-tolerant crops, plants or trees should be selected.
50. When moderate to highly saline waters have to be used then soil management practices may be adopted to reduce the effect of saline water on growth i.e. with the use of organic and inorganic fertilizers, plantation on ridges, beds etc.
51. Inorganic fertilizers (i.e. phosphorus and nitrogenous fertilizer) should be applied to increase the growth and production of vegetables.
52. Soil moisture should be conserved by using different types of mulches so as to reduce the application of irrigation water.
53. A maximum amount of rainwater should be harvested and stored for cultivation of precious vegetables.
54. All farmers should grow vegetables for domestic consumption by planting a number of summer and winter vegetables. The irrigation could come from tobas using manual means.
55. The practice of growing vegetables for domestic consumption by the farmers will diversify their food sources and supply protein, vitamins and carbohydrate-rich food for the family that will in turn improve their health.

8.1 Comments on project achievements contribution to improving policies for dry land management

The assessment methodology project helped in identifying the status of land, water and plant resources in the marginal drylands of Lal Sohanra Biosphere Reserve and its vicinity. The assessment also identified major economic constraints in the form of unsustainable practices, and the prevalence of poverty issues in the project area. Primary measures to conserve the environment for ensuring sustainable development were implemented. These specific issues required research in order to propose sustainable solutions. Income-generating activities for introduction were also identified.

Policy-makers were kept informed on the problems and solutions of drylands with the full complement of information emanating from the project activities. Moreover, the policy-makers realized that by harvesting and developing the potential of resources in the drylands, and by finding solutions to the many issues, the area could benefit in the form of higher incomes and environment conservation. The project research team tested out sustainable management strategies in Lal Sohanra Biosphere Reserve and highlighted specific problems directly linking social concerns and the impact of drought in the area. The current economic resources in the community were also identified. Communities were involved and able to share their views to help solve the economic and environmental issues, and more realistically understand the dynamics of the project area. This helped policy-makers to identify and initiate better development projects in the area as regards water resources, roads, education, and electricity and so on. The income-generating activities i.e. saline fish farming, vegetable production with saline water, as well as moisture conservation techniques provide an alternative livelihood for dryland communities. These actions opened up possibilities for the policy maker to initiate development projects that strengthen and diversify income sources for the local community so as to improve their socio-economic conditions and bring them to par with the developed parts of the country. Today, policy-makers are considering utilizing the hidden potential of marginal dryland resources as a contribution to the national economy instead of thinking of these communities as a burden to other developed parts of the country.

9. National seminars

1. Saline fish farming: an alternative livelihood for the people of dryland Lal Sohanra Biosphere Reserve was held on the 8 November 2005 and was attended by 200 participants.

2. The use of saline water for vegetable production under different moisture conservation techniques in the drylands of Lal Sohanra Biosphere Reserve was held on the 11 September 2006 and was attended by 110 participants.

3. Participatory fish farming using saline groundwater and rainwater in the dryland areas of the Cholistan desert took place in August 2007 and was attended by 100 participants.

9.1 Outcome of the seminars

Prior to the seminar, the local people in the project site could not envisage the possibility of fish farming in the desert. During the seminar, they carefully listened to the purpose of the experiment – it should be noted that the idea of saline fish farming in the desert was unheard of to them – and they were surprised yet pleased to see fish weighing about 1kg during their visit to the experimental sites. As a result, they were anxious to learn how to establish fish farms on their own land. They approached the PCRWR researchers to learn about the procedure of farm development. Even the fishery department of the Punjab government at Bahawalpur approached the PCRWR researchers to obtain the results and comprehend the prospects of saline fish farming in the desert. They offered their full cooperation to farmers interested in establishing fish farms using saline water, and for a low concessional charge they were able to set up a hatchery. Moreover, the concept of saline fish farming is gradually gaining popularity. The water source was seen as the principal problem faced by the farmers in initiating the fish farm activities. The farmers view is that the government should install the tubewells that pump groundwater as well as provide the water for the fish farms while charging only a nominal payment because of the level of poverty experienced by local people who cannot afford the initial large investment for the tubewells.

Moreover, vegetable production in the drylands using saline water irrigation was also unheard of by the local people because they were led to believe that only water from the river via the canals could be used for vegetable irrigation and they never considered that saline water could be used instead. At the seminar they learnt that a number of vegetables could be grown even with highly saline water. They were keen to learn about the method of sowing, irrigation and the application of fertilizers to successfully grow vegetables to improve the nutritional value of the diet. Today, farmers have now started cultivating vegetables at their residence or agri-farms i.e. small scale farms that meet their domestic needs. Furthermore, the results have reinforced their opinion that vegetable farming can be a source of income. The overall outcome of the seminars is that the local people have started to think about other income-generating activities other than simply livestock farming and handicrafts.

10. Research institution and team composition

10.1 Research institution

The Pakistan Council of Research in Water Resources
Regional Office 29-Sajid Awan Colony
Bahawalpur, Pakistan.

10.2 Team composition

Team leader: Ch. Muhammad Akram, Chief Researcher, Desertification PCRWR, Islamabad.
National Coordinator: Dr. Muhammad Akram Kahlown, Chairman, PCRWR, Islamabad.

Team members

Mr. Zamir Ahmed Soomro, Senior Researcher, Regional Director, PCRWR, Bahawalpur.
Mr. Muhammad Tahir Saleem, Junior Researcher, Assistant Research Officer, PCRWR, Bahawalpur.

Name and function of team leader

Ch. Muhammad Akram, Chief Research (Desertification) PCRWR, Islamabad.

1. To develop research proposals that consider the needs and requirements of the local people and the project site in order to raise the socio-economic conditions of the area.
2. To plan, design and draft the research proposals submitted within the framework of the SUMAMAD project.
3. To prepare the implementation of the proposals in the field, and list parameters to be recorded during the period of study.
4. To provide guidance to the research team in the collection of data, and process and report the data in the final report.
5. To finalize the research data undertaken in the study as well as the research results for inclusion in the report.

6. To prepare the technical papers presented in the SUMAMAD seminars by the National Coordinator.

11. Publications as a result of SUMAMAD

Akram, M. 2005. *Rainwater harvesting in the proceedings of the Regional Workshop on Training of Trainers on Management of Artificial Recharge and Rainwater Harvesting Projects* held at Lahore Pakistan 25 April – 2 May 2005 organized by PCRWR & UNESCO Tehran Office. pp. 95–102.

Kahlown, M.A., Akram, M & Soomro, Z.A. 2006. Saline fish farming: An alternative livelihood for the people of dryland Lal-Sohanra Biosphere Reserve, Pakistan. In: *Proceedings of the fourth UNESCO-MAB/ICARDA, UNU Workshop on Sustainable management of marginal drylands held at Islamabad Pakistan 27–31 January, 2006*. pp.109–120.

Akram, M. Kahlown, M.A. & Soomro, Z.A. Desertification control for sustainable land-use of Cholistan desert, Pakistan. In: *Proceedings of the International Scientific Conference on Desertification and drylands Research – The Future of Drylands*, Tunis, Tunisia 19–21 June, 2006. [In press]

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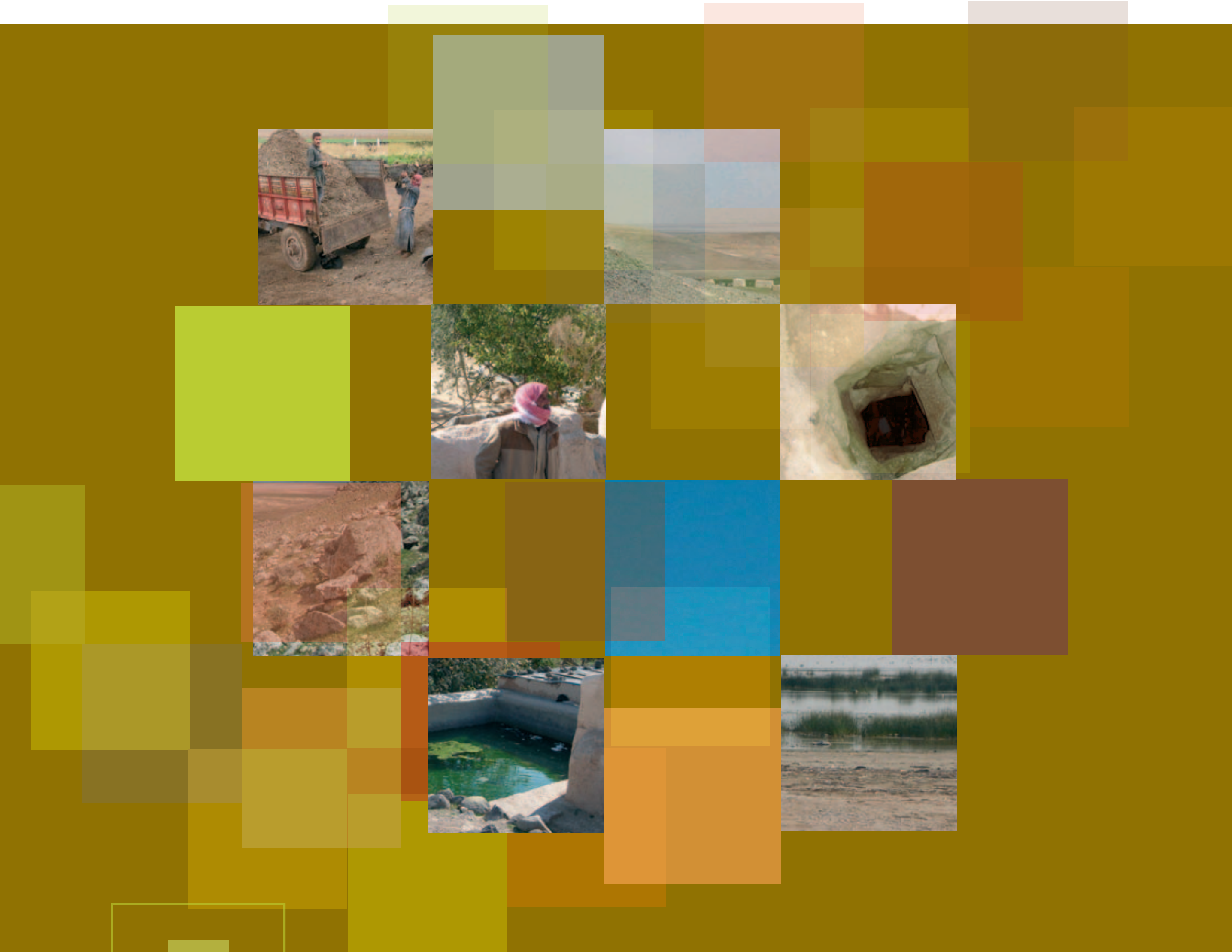

7

Khanasser Valley

Syria

By R.J. Thomas, A. Bruggeman, F. Turkelboom, R. La Rovere,
A. Aw-Hassan, E. Luijendijk, H. El-Dessougi, S. Waheibi, Z. Masri
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1. Main challenges at the project site

As outlined in the introduction, drylands face a number of converging trends that include:

- High population growth rates of up to 3% and a demographic pattern that will result in large numbers of young people entering the job markets over the next 10–20 years.
- Regions that are already water scarce and will be increasingly so especially if climate change predictions are correct and the regions become hotter and drier.
- Increasing dependency on grain imports for food security.
- Increasing desertification and loss of biodiversity in some of the major centres of plant diversity.
- Increasing out-migration of males from rural areas that will result in the loss of traditional farming systems and greater reliance on women as heads of households.
- Problems of access to international markets as a result of international trade policies and subsidies.

The cause of desertification in any particular locality is context specific and is usually a combination of socio-economic and biophysical factors (e.g. Geist and Lambin, 2004).

In the Khanasser Valley these factors include insufficient rainfall for growing a rainfed crop in most years. As a consequence, a large number of wells have been installed in the valley during the last fifteen years to supplement the rainfall. However, in this dry environment the upper aquifer system receives little recharge. Consequently, the groundwater table has dropped substantially during the last two decades. The majority of the irrigation wells now tap groundwater that is too saline to be used for irrigation. Along the hill ranges and in the northeast and west, the water quality is good but extremely limited especially in summer. Most households buy drinking water from the government pipeline in the very north of the Valley. The water is brought to the houses by tractor-pulled tanks. High intensity rainfall events occur irregularly causing destructive floods and loss of fertile topsoil. However, these floods may also provide critical water to the soils in the valley. During the hot dry summer months, wind erosion affects the bare crop land, which is left susceptible after stubble grazing by sheep. Other major factors include decreasing productivity, limited experience with non-traditional enterprises, increased population pressure and cash flow problems, socio-cultural decline through out-migration and loss of cultural heritage, limited research and extension services, lack of local markets and market information, and unpredictable price fluctuations of farm products.

The following constraints were identified by farmers in the valley:

- Lack of sufficient rainfall and water for irrigation.
- Shortage of crop varieties (mainly barley) which are resistant to diseases and drought.

- Financial constraints to meet customary expenses, to establish and adopt new technologies, and to purchase inputs.
- Widespread lack of information on appropriate technical knowledge.
- Unclear land property rights and policies that discourage investments, contributing to resource use conflicts, and lack of sound compensatory measures for affected groups.

2. Environmental characteristics of the study site

2.1 Geographical location

The Khanasser Valley is located approximately 80 km south-east of Aleppo city. The valley is oriented in a north-south direction between the hill ranges of the Jebel Shbeith in the east and the Jebel Al-Hass in the west (Figure 1). The elevation of the valley is 300 to 400 m above sea level with the boundary hillsides reaching 600 m.

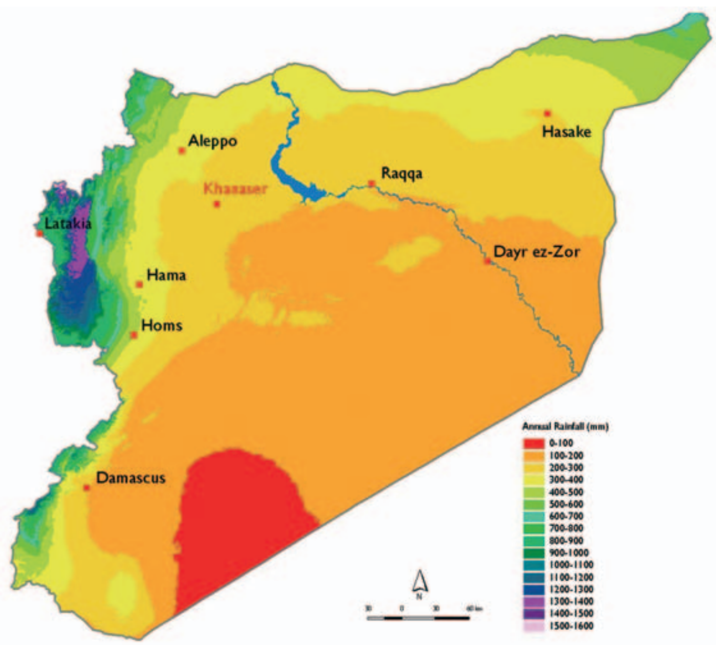

Figure 1. Average annual rainfall in Syria and location of study area.

2.2 Major habitat

The agricultural area and the natural rangelands of the steppe (*badia*) meet in the valley. The northern part of the valley drains towards the Jabbul Salt Lake and the southern part drains towards the Adami depression in the steppe. Large flocks of sheep that graze the steppe during the winter months cross the valley in early summer on their way to greener pastures. The Jabbul Lake is a rest place for migrating birds. It has recently been named as an environmentally protected area. The diverse bio-physical features and socio-economic conditions create a dynamic ecosystem in the valley and surrounding areas.

Figure 2 shows the marked changes in land-use over recent times with irrigated and rainfed cropping systems replacing rangelands over the majority of the area. This intensification of land-use has resulted in environmental problems of soil erosion by wind and decreasing groundwater levels and quality. Figure 3 shows a general view of the degraded landscape in the valley.

2.3 Climate

The valley has long, hot and dry summers. Rain falls from September to May with a peak during December and January. The long-term annual rainfall in Khanasser village is approximately 220 mm. Precipitation is slightly higher on the Jebel Al-Hass and is lower in a southeasterly direction towards the steppe. The rainfall displays high annual and inter-annual variability. Observed annual extremes for the last 45 years are 93 and 393 mm. Reference evapotranspiration is approximately 2,000 mm/yr.

2.4 Geomorphology and soils

The valley is a gently undulating plain with a network of wide, dry channels. The basalt covered hill ranges of Jebel Al-Hass and Jebel Shbeith form gently rolling plateaus,

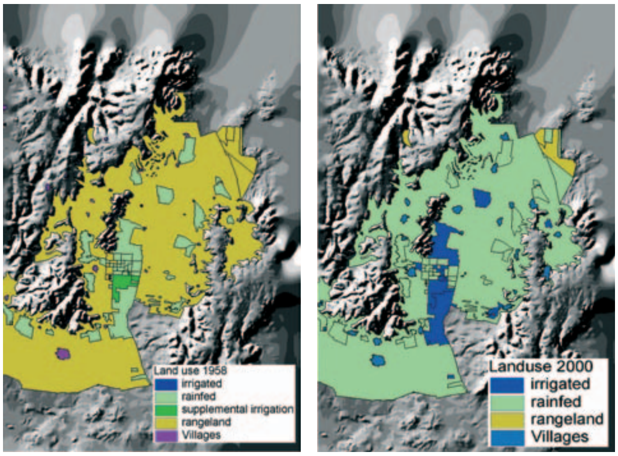

Figure 2. Changes in land-use in the Khanasser Valley from 1958 to 2000.

which end in well-defined steep scarps towards the valley. The slopes are covered with stones and incised with v-shaped erosion channels.

The soils on the slopes are of variable thickness but are generally very shallow. Soil depths range from less than 1 m at the foot of the slopes to 16 m in the centre of the valley. The soils in the valley floor are fine and moderately textured dark-brown to brown Calcisols, Gypsisols, Leptisols and Cambisols. The soils of the Jebel Al-Hass and Jebel Shbeith plateaus are Inceptisols. In general, the soils are well drained and have high infiltration capacity.

2.5 Major vegetation types

The flora of the Al-Hass and Shbeit hill ranges contain 234 species belonging to 40 families and 153 genera (Oudat *et al*., 2005). Annual and biennial species are dominant as far as their number is concerned, followed by perennials, semi-shrubs, trees (10 species) and one species of shrub (*Anagyris foetida*). The plant community on the hill slopes is dominated by *Hordeum murinum, Teucrium polium* and *Noaea mucronata*. The study area is classified as a Mediterranean-Irano-Turanian botanical region. The climax vegetation of the region was probably dry steppe-forest. Cultivation and heavy grazing has changed the vegetation. In some sites

Figure 3. A general view of the degraded landscape in the valley.

around settlements, the vegetation has been severely degraded, resulting in an extremely poor *Peganum harmala-Carex stenophlla* community with no ability to sustain livestock.

Further details of the area have been reported elsewhere (Ruysschaert, 2001, Aw-Hassan *et al*., 2002; Thomas *et al*., 2004).

3. Socio-economic characteristics

3.1 Number of human population and families

Fifty-eight villages and communities inhabit Khanasser Valley and the adjacent fringes of the Jebel Al-Hass and *badia*. There is a large variation among the number of resident households per village ranging from 5 to 270 households. The average number of resident households was estimated at 50 households per village. This number is higher in the Khanasser Valley than in the steppe. The total population of the 58 villages is about 37,000 persons.

3.2 Ethnic origin and composition

The population of Khanasser Valley consists mainly of farmers of bedouin origin such as the Fid'an tribe.

Khanasser village has a large number of Circassians who settled there in the beginning of last century.

3.3 Major economic activities

The majority of the population in Khanasser Valley is involved in agricultural activities. There are three main types of agricultural production systems in the valley: rainfed farming, irrigated farming, and livestock rearing (Figure 2). Most households practice a combination of crop production and livestock rearing. Rainfed farming, with barley as the dominant crop, occupies the major part of the arable land. Off-farm activities are very important in providing sufficient income for the families in this resource poor area. About 43% of households in the Khanasser area have one or more members working as off-farm labour, 15% of households had members working as labour in cities, and 16% of households had members working outside Syria.

In terms of livelihoods the population can be classified into three main typologies; 'labourers', 'agriculturists' and 'pastoralists' (La Rovere *et al*., 2006). On average, labourers own 3.5 ha of land and mostly rely on off-farm earnings. Agriculturists essentially integrate crops, fattening, and waged labour, while the pastoralists are extensive herders, migrate for wages, or in some cases, engage in intensive lamb fattening. Most households living in the Khanasser area depend on earnings from sales of crops for less than one fourth of their total income, making off-farm labour and animal production their major sources of income. Average per capita income is $1–1.5/day. About 45% of people, including the agriculturists and the pastoralists with off-farm earnings, are relatively better off. The former can competitively engage in farming and access agricultural technologies. The poorest households, comprising 30% of the population, are the landless with livelihoods mainly based on off-farm wages, which are often insufficient to allow them to emerge from poverty. The pastoralists with extensive herds in remote steppe areas and no off-farm options are also among the poorest. Intermediate groups (about 25% of all people) are the labourers with assets (land and/or family labour) that allow them to engage productively in farming.

4. Conservation of natural resources, community development and scientific information

Land degradation is occurring in the valley albeit as a slow variable as a result of soil fertility mining (lack of inputs, export of animal manures to horticultural areas), over-grazing, wind, water and tillage erosion, salinization and water pollution. However the inhabitants do not perceive land degradation as a major threat to their livelihoods because:

- the rate and impact of degradation is slow;
- irregular rainfall patterns mask the effects of degradation;
- they are more concerned about meeting immediate needs than long-term sustainability;
- investments in natural resource management are considered uneconomic; and
- they have become accustomed to a degraded environment.

This lack of awareness or major concern over the degradation of land resources is common in many marginal drylands.

The state of the groundwater resources in the study area is poorly known. Most hydrogeological research dates to the 1970s. In the mean time, the use of groundwater for irrigation has greatly expanded as a result of the introduction of modern well drilling equipment, diesel pumps and government incentives, such as subsidized fuel. This has altered the state of the groundwater resources significantly.

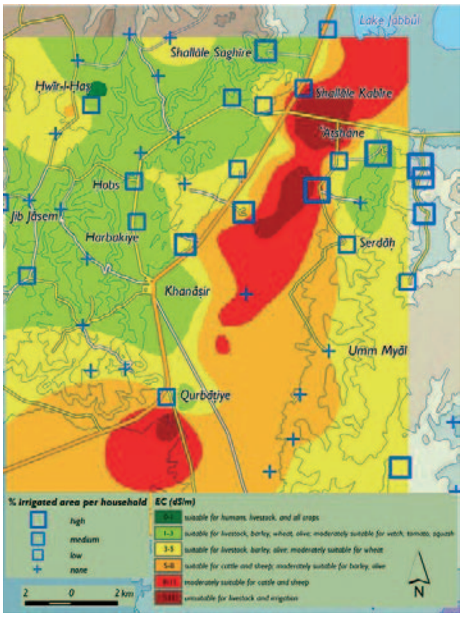

Figure 4. Map of groundwater salinity levels and irrigated areas per household in the Khanasser Valley.

There are two water bearing layers (aquifers) in the region, the upper aquifer system, which is located between the surface and a depth of around 200 m, and the deep aquifer located below depths of 350 to 500 m. The groundwater contained in the upper aquifer system varies greatly in quality. In the low lying areas electro-conductivity (EC) can be as high as 30 dS/m, but along the hill slopes the salinity is low; the EC does not exceed 3 dS/m. Groundwater of the deep aquifer has elevated salt contents with EC's ranging from 7 to 12 dS/m. More recent studies have reported the salinity levels in greater detail (Asfahani, 2007). Figure 4 shows an approximate map of soil salinity levels.

At present, groundwater levels roughly follow the topography varying from 1 to 100 m below the surface. A comparison of present and past groundwater levels, using data of twelve observation wells reported by Gruzghiprovodkhoz (1982), shows that the groundwater level has declined on average between 10 and 40 m in approximately 30 years. The largest decline has occurred in the Qweiq River Valley and in the Bagat-Rabaia'a and Seyaleh areas on the south-east side of the Jebel Al Hass, where groundwater levels have declined approximately 40 to 80 m in the past thirty years (Luijendijk & Bruggeman, 2007).

In most villages in the study area, ancient wells, referred to as Roman wells, and hand-dug, large-diameter Arabic wells were found to be dry. In the village of Khanasser, the qanat has stopped functioning due to the decline in groundwater levels. Qanats are ancient irrigation structures that tap groundwater in hills or alluvial valleys through the construction of sloping underground channels. The qanat in Khanasser was recovered and restored by pioneer farmers in 1938. However it ceased to function in 1977 because the groundwater level had dropped below the base of the qanat. Although the demise of the qanat has been caused by pumping by farmers themselves, they still reminisce about the flow of the qanat and hope that it could be brought back.

The observed decline in groundwater levels seems to be the largest in the more permeable aquifers. High permeability permits high well yields, which promote extensive exploitation and rapid depletion of available groundwater resources. Aquifers therefore seem to be a victim of their own success. In contrast, on the basalt plateau, where maximum well yields are often as low as 1 l/sec, groundwater levels are reported to be stable by villagers.

The land-users in the valley are aware of the declining water resources but there are little or no incentives to conserve their dwindling supply. This situation is probably made worse by the fact that irrigation canals from the Euphrates river are gradually extending southwards into bordering areas with the expectation that eventually these canals may serve the Khanasser Valley.

ICARDA has worked together with local and national institutions in this area for over twenty years and there is a great deal of scientific information available on the soils, water natural biodiversity, and the agro-nomy of the prevailing integrated crop-livestock systems. It is only over the last five years or so that a more holistic integrated approach has been taken that considers the biophysical and socio-economic conditions. This approach was detailed in the earlier SUMAMAD publication (Thomas *et al*., 2004) and elsewhere (Turkelboom *et al*., 2003; Campbell *et al*., 2006; Thomas and Turkelboom, 2007). Historically, the area was occupied at least as far back as the Modern Stone Age and was a border area of the Roman Empire with the Persians. Arab tribes then occupied the area until recent times and during the Ottoman Period the land was mainly fallowed. Movements of people in and out of the area have been common with current populations settling there at the beginning of the last century. Social networks are strongly based on tribal or family ties.

As indicated above, although the populations have been living in the area for generations the perception of land degradation is not particularly strong even though it is very evident from the exiting landscapes (Figure 3).

5. Practices implemented for soil and water conservation

In this project, the work focused on the sustainable use of groundwater and on nutrient conservation.

5.1 Sustainable use of groundwater

5.1.1 Assessment of the potential of small dams to improve water supplies

As part of efforts to communicate the results of past water resources studies to policy makers and communities in the area, a stakeholder meeting was organized for farmers, researchers and representatives of development agencies and the Syrian government. During this workshop a number of options for sustainable management of water supply were discussed. The workshop participants ranked 'water harvesting by making small dams to recharge the groundwater' as the most important water-related issue (Tubeileh *et al*., 2005). Therefore, this option was selected for further study.

In dry areas, surface water resources are usually limited to short duration flows through wadis following heavy rainfall events. A significant part of this water runs off unused towards local depressions, saline flats (*sabkhas*) or salt lakes, and a large part of this water is subsequently lost to evaporation. Thus, harvesting this source of water has great potential for increasing water supply in dry areas. This water can be captured by dams in wadis and stored in surface reservoirs. Alternatively, the water can be utilized for infiltration into the groundwater system, which is termed artificial recharge.

Subsurface storage of water has several advantages over surface water storage. In dry areas, evaporation loss of water from surface reservoirs amounts to values of approximately 2 m per year. Other disadvantages of surface reservoirs are sediment accumulation in the reservoir and potential of structural failure (Bouwer, 2002 and references therein). In addition, the quality of water in the reservoir is often low while the subsurface storage benefits from natural purification in the aquifer (Bouwer, 2002; Gale *et al*., 2002). Groundwater can also serve as a buffer to ensure water supply during dry periods. Due to the large ratio of water stored in a groundwater reservoir versus annual inflows and outflows, the impact of short dry periods on groundwater supply is limited.

5.1.1.1 Objectives

The objectives of this study were: 1) to assess sustainable rates of groundwater use; 2) to explore the potential and constraints of small dams in marginal drylands; and 3) to identify the key parameters that affect the potential suitability of sites for small recharge dams. The study attempted to integrate socio-economic and biophysical (hydrological) considerations.

5.1.1.2 Methodology

Firstly, a field survey was undertaken to investigate the potential of small dams in the study area. Socio-economic potentials and constraints were explored by open interviews with local farmers with the help of a local community facilitator. Secondly, the processes that affect the functioning of small recharge dams and the effects of small earth dams on the hydrological system were reviewed, and the factors that control these processes identified and evaluated for the study area. This stage of the research focused on recharge check dams rather than small reservoir dams. The identification of factors was based on expert knowledge and information from literature (e.g., Bouwer, 2002; Gale *et al*., 2002). Data and knowledge of the study area was obtained during previous research activities undertaken by ICARDA, as documented in Bruggeman *et al*. (2007) and Luijendijk and Bruggeman (2007).

5.1.2 Site selection criteria for recharge check dams and evaluation

With respect to the functioning of recharge dams, three main processes could be distinguished: 1) rainfall-runoff; 2) infiltration and recharge; and 3) management and use. The parameters that control these processes, and information about these parameters in the study area, are discussed below.

5.1.2.1 Rainfall-runoff

The amount of runoff captured determines the amount of water available for infiltration to the groundwater table. This depends on the following factors:

Rainfall: the amount, duration, and intensity of rainfall affect the amount of runoff generated in a catchment. However, few locations have long-term records with intensity data. Therefore, the long-term average annual precipitation could be used as an indicator. In the study area, due to the altitude effect and the general trend of decreasing precipitation in the southeasterly direction in this region of Syria (De Pauw, 2001; Bruggeman, 2007) the average rainfall is slightly higher in the Jebel Al Hass plateau than the Jebel Shbayth plateau (260 against 230 mm yr^{-1}). Therefore, recharge dams in this region are likely to capture more runoff water.

Characteristics of catchment area: factors that affect how much of the rain will exit a catchment as surface runoff include the characteristics of the soil (depth and texture), the land cover/use, and the slope. In the study area, the shallow soils on the stony slopes of the basalt plateaus, with a sparse cover of natural vegetation, have the highest runoff potential. The frequent occurrence of gullies on the stony slopes, which often disperse in the flatter cropland areas downstream, is an indication of the runoff potential of the slopes.

Size of catchment area: The larger the contributing area upstream of the recharge dam, the higher the volume of runoff water. However, if the contributing area is too large the peak flows will be higher and the development of a structure will become more costly. The characters of the catchment area could be used to estimate a runoff factor, from which, when combined with rainfall data, peak flows and runoff volumes, could be estimated. This would allow the establishment of criteria for a suitable catchment area size. Catchment areas can be automatically computed from a digital elevation model (DEM) using GIS tools.

Location of communities: The design of a hydraulic structure is based on runoff events that have a certain chance of occurrence. The selection of a design event depends not only on the economic life time of a structure, but also on the damages that may occur in case of failure. Thus, to avoid high construction costs, recharge dams should not be located in places where failure may cause loss of life or damage to homes. Therefore, recharge dams should not be located directly upstream of communities.

5.1.2.2 Infiltration and recharge

The captured runoff should be able to infiltrate and percolate to the groundwater table. This depends on the following factors:

Wadi dimensions: the dam should be able to capture enough water to drive the infiltration and percolation to the groundwater table. The percolation velocity of water rises with increasing water level in the reservoir (Bouwer, 2002). Thus, wadis that are relatively deep and narrow allow higher percolation velocities, whereby a larger portion can percolate to the groundwater table, and less water is lost to evaporation. In shallow reservoirs, the percolation velocity is low and most of the water is retained by the unsaturated zone rather than percolate to the groundwater table. In the study area, the deeper wadi courses in the basalt plateau and the adjacent slopes offer better opportunities than the relatively shallow wadis in the valley-floor.

Depth to water table: the groundwater level should be located at shallow depths to allow percolation of water to the water table. In areas with a deep water table, the infiltrated water will only replenish the thick unsaturated zone, and part of this water will be subsequently lost to evapotranspiration in the following dry season. Water levels are generally located at depths of 40 m or more on the basalt plateau, while in the slopes towards the valley and the valley floor, the water level is usually located at depths of 5 to 30 m below the surface. Thus, these locations are more suitable for dam locations.

Hydraulic conductivity of the vadose zone: the hydraulic conductivity of the vadose zone, i.e. the soil and bedrock that are located above the groundwater table, should be sufficient to permit the water to percolate downwards and to avoid perched water tables. In the study area, the hydraulic conductivity of the Quaternary alluvial sediments, which are located in the valley floor, is relatively high – estimates range from 1 to 370 m day^{-1} – whereas the hydraulic conductivity of the bedrock in the study area is relatively low – estimates range from 0.6 to 1.7 m day^{-1} (Kadkoy & Schweers, 2007). However, field observations indicated that fractures locally greatly enhance conductivity in the limestone formation. Alluvial sediments with a high conductivity are found in the larger wadis. The texture of the sediments in the wadi is coarser in the upstream areas than downstream areas and therefore the upstream areas are more suitable locations for recharge dams.

Aquifer transmissivity: The aquifer should be sufficiently transmissive to accommodate lateral flow of the infiltrated water away from the recharge area without forming high groundwater mounds that interfere with the infiltration process and could undermine the structure (Bouwer, 2002). The transmissivity is the product of the thickness of the aquifer and the conductivity. The distribution of the transmissivity in the study area follows that of the hydraulic conductivity, as discussed above.

5.1.2.3 Water management and use

The suitability of locations for recharge dams from the perspective of groundwater use depends on the intended uses of the water. It should also be considered that under most conditions significant effects of artificial recharge structures on groundwater levels remain confined to a short distance from the recharge structure (i.e. Gale *et al.*, 2002). Thus, the following two factors were identified:

Groundwater quality: Although rainwater contains very little dissolved solutes, once it becomes surface runoff it will collect sediments, nutrients, and other pollutants. Because the percolation process of groundwater recharge filters the water, the recharged groundwater is generally of high quality. Thus, one would generally not want to mix this water with poor quality groundwater resources. Any induced groundwater recharge in the areas in the valley floor due to the high salinity of the sediments and groundwater in this area would render the water unsuitable for irrigation. The electrical conductivity (EC) of groundwater in this area ranges from 5 to 20 dS m^{-1}. The salinity is caused by the occurrence of evaporitic sediments in the Quaternary formation located in the centre of the Valley (Technoexport, 1966; Asfahani, 2007; Abu Zakhem, 2007). Groundwater is only suitable for domestic use in the areas near the Jebel Al Hass plateau, where EC's range from 0.5 to 1.5 dS m^{-1}. In the area near the Jebel Shbayth plateau, the water is slightly more saline but still suitable for irrigation. The EC of groundwater in this region ranges from 2 to 4 dS m^{-1}.

Water users: Considering the generally short range of influence of the recharged groundwater, recharge dams should be located close to existing wells. Alternatively, new wells could be established. If the water is intended for domestic use, the well should be located close to a community where this water can be used. If the water is intended to be used for irrigation, the dam should be close to existing irrigated areas or to sites that are suitable for irrigation. Because groundwater is a common pool resource and captured resources are difficult to quantify, the intended users group should have a mechanism for managing water use and solving potential disputes and problems. A number of communities with good leadership have been identified during ICARDA's integrated research activities in Khanasser Valley. However, further socio-economic assessments would be needed.

5.1.3 Results and discussion

5.1.3.1 Assess sustainable rates of groundwater use

The trends in groundwater levels in the Khanasser Valley

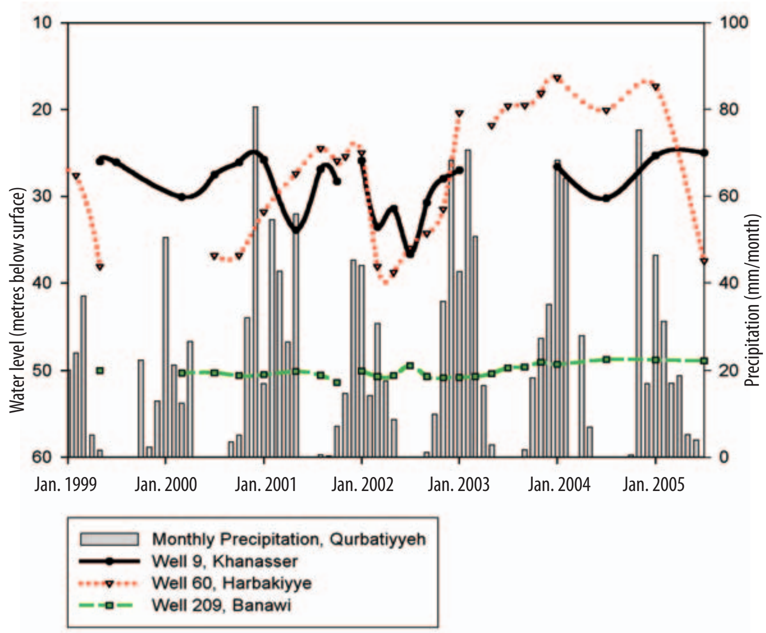

Figure 5. Precipitation and groundwater levels in the Khanasser Valley and adjacent basalt plateau.

and the adjoining basalt plateau during 1999–2005 is illustrated in Figure 5. On the Jebel Al Hass basalt plateau (Well 209) because of the absence of pumping in this area, water levels have remained relatively stable. In general, because of the low permeability of the chalky Paleogene limestone bedrock, which underlies the basalt layer, wells on the basalt plateau do not yield sufficient water to be utilized for irrigation.

In the valley floor, groundwater pumping is much more prevalent; 138 wells that tapped fractured Paleogene limestone or Quaternary gravels and sands pumped an estimated 1.3 106 m^3/yr in the 2002/2003 season (Schweers, 2007). This volume is approximately equal to the annual volume of groundwater recharge (Luijendijk, 2007), which questions the long-term sustainability of the present rate of pumping. Pumping often causes high fluctuations in groundwater levels (Well 9 and 60 in Figure 5). In dry years, such as 1999/2000 and 2002/2003, to compensate for the lack of rainfall farmers tend to increase pumping during the rainfed winter cropping season. This has lead to sharp decreases in water levels, and in some cases, the drying up of wells.

The high density of production wells in the study area makes it difficult to assess long-term water level trends. Water levels in observation wells are influenced by short term fluctuations caused by neighbouring production wells. Therefore a numerical flow model (MODFLOW-2000) was used to improve our understanding of the dynamics of the groundwater system in the Khanasser Valley and the reaction of this system to external influences such as pumping. The model was calibrated to match groundwater levels, and flow observations taken in the 1970s, prior to the development of the groundwater resources in the valley, were supplemented by a number of recent observations from locations where groundwater levels were unlikely to have been substantially affected by pumping. Parameter uncertainty was taken into account by calibration of the model for a range of recharge values. The optimum calibrated parameters gave an average recharge over the study area of 1.0% of the long-term average annual precipitation, with an uncertainty range of 0.24% to 2.4%.

Simulation of the impact of present pumping rates (1.3 $x10^6$ m^3yr^{-1}) indicated that these pumping rates would cause an inflow of water from the Jabbul Sabkhah (saline depression) after 15 to 62 years of pumping, and should therefore be considered unsustainable. An example of the change of flow volumes over time following the initiation of pumping is presented in Figure 6. Initially, pumping is mainly compensated by a decrease of water stored in the aquifer – the system stabilizes at a later stage. The change in storage slows down and evapotranspiration and outflow into Jabbul Sabkhah are both reduced, as compared to the initial steady-state situation. The slight decrease of pumping in the first 150 years is caused by the drying up of a number of wells.

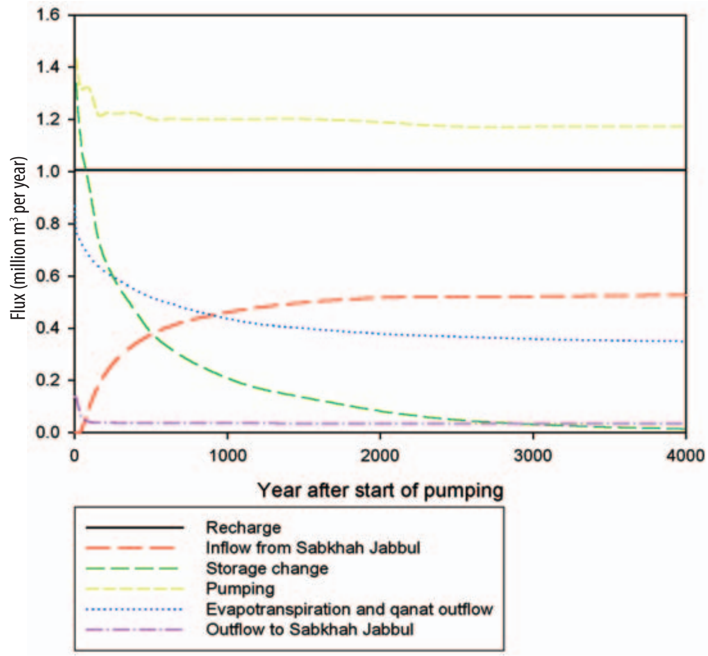

Figure 6. Example of simulated changes in flow volumes over time as a response to current pumping rates.

Simulation of the current climate scenario indicated that the groundwater levels are much more vulnerable to changes in pumping rates than to droughts. The changes in groundwater level over a 30-year simulation generally remained within a range of 0.4 m. Water level declines were mainly confined to the basalt plateaus. Testing of sustainable scenarios indicated that a uniform redistribution of the production wells, in which each village was assigned one well, resulted in higher sustainable pumping rates than could be obtained by the current production wells. Estimated sustainable pumping volumes per village were within the range of 800 to 29,740 m^3 yr^{-1}.

5.1.4 The potential and constraints of small dams and community experiences with small dams

5.1.4.1 Site description

Two small earth dams were located in the study area in a wadi near the village of Jubb Allays. The first dam was constructed three years ago and consists of a small earthen dam reinforced with stones with a height of approximately 1.5 m. Water was captured in a reservoir behind the dam and was pumped out to irrigate 1 ha of wheat.

The second dam, located downstream from the first, was a diversion dam. The dam was made from sediment taken from the wadi-bed and was approximately 1.5 m high and 50 m long. The dam was constructed six years ago. The farmland of the owner is located on either side of the wadi. The water captured by the dam was used to flood the fields adjacent to the wadi, and provides additional moisture for the crops. The farmers hired a manned bulldozer to make the dams. The construction costs were 2,000 and 3,500 Syrian Lira (37 and 65 USD), respectively.

In addition, a flood diversion dam was located near the village of Harbakiyah. This dam was constructed by the government and construction was completed in the summer of 2001. This wadi drains a 28 km^2 watershed. The construction consists of a concrete dam, which diverts water to a pond that has been constructed at a short distance from the wadi. The total capacity of the reservoir is 50,000 m^3. Field observations indicate that the reservoir fills after rainfall events of 20 mm per day or more, which occur on average 1.2 times per year (unpublished data, ICARDA).

5.1.4.2 Potentials

Both small dams provided additional water for wheat and increased the income of the farmers. The cost of the structures was very low and the structures were easy to maintain. The return on investment was high. The owners reported an increase in yield of 1 to 2.5 ton of wheat per ha in years with sufficient runoff, which corresponds to an additional income of approximately 10,000 to 25,000 SL (180 to 450 USD).

It was not known to what extent the establishment of these dams had contributed to additional recharge of the groundwater. Although none of the dams were designed for this purpose, it is likely that these dams contribute to additional recharge of the alluvial aquifer that is connected to the wadi. The reservoir in Harbakiyah was built as a lined storage structure, but during the few times it was filled the reservoir seemed to lose water. Farmers in Harbakiyah think that their groundwater resources have been improved since the construction of the dam but this could also be due to a reduction in groundwater-irrigated fields in summer, and years with higher rainfall.

Whether the dams enhance recharge to the underlying Paleogene limestone formation depends on the occurrence of fractures as the permeability of the bedrock in this area is very low. However, in all cases there were no activities to remove sediment from the reservoir to prevent a clogging layer, which significantly reduces the potential for groundwater recharge.

5.1.4.3 Identification of constraints that affect the potential suitability of sites for small recharge dams

The owners of the two earth dams perceived the fact that runoff events in that area occurred only once every two or three years as a constraint to the adoption of this technique. Also during dry years, when supplemental irrigation of winter crops becomes more critical, less or no runoff will be harvested. However, in both cases, the return on investment was already reached after the first good runoff event. The flood water harvesting method relies on the farmer having sufficient land close to the wadi. According to the farmer, this is generally not the case in the area where the fields are often very small. In addition, the suitability of the technique depends on the topography of the wadi and the adjacent fields. Because the wadi runoff in these areas is generally not used, there were no conflicts with potential downstream users.

One of the two earth dams was not maintained last year because the owner had temporarily moved to Lebanon for work. Any water captured in the reservoir was not used.

The reservoir in Harbakiyah was designed to provide water for livestock. Although one farmer has expressed interest in using the water for irrigation, they are not allowed to use the water for this purpose. However, farmers are concerned that the quality of the water is not sufficient for sheep drinking and are currently not using the water. Van der Meijden (2004) reported similar farmers' concerns for a reservoir on the northern site of the Jebel Al Hass.

5.1.5 Conclusions

Communities in the research area have expressed their interest in harvesting runoff water for irrigation. Experiences of two farmers indicated that small earth dams could be established at low cost and are relatively easy to maintain. The captured water was used for irrigation. The increased crop yield after irrigation with the captured water was sufficient to cover to cost of establishing the dam after one season.

A review of the factors that affect the functioning of small recharge dams combined with available information and knowledge of the study area provided an initial assessment of promising areas for recharge check dams in the Khanasser Valley study area. With the help of available information and GIS data layers for the study area, these potential locations will be classified and mapped. However, a hydrologic assessment needs to be carried out to confirm the final suitability of the locations. The preliminary findings of this study have been discussed with representatives of the Syrian Ministry of Irrigation. The suggested introduction of small recharge check dams was well received and will be considered an important option for the development of the water resources in Khanasser Valley. The ministry has requested ICARDA's cooperation on this subject.

6. Income-generating activities through the participatory action research on the conservation of nutrients

Previous work on the use of a relatively new crop, cumin, and its economics as an alternative income-generating option was reported earlier (Thomas *et al.*, 2005).

Figure 7. Farmers collecting sheep manure for export from the valley.

Here we focus on the use of participatory approaches to encourage technology development by farmers themselves that shift research from a supply-driven mode to more demand-driven technology development. To achieve this, the project organized a series of workshops to increase the participation of farmers in the research process. This resulted in the creation of a number of farmer interest groups (FIGs) that were previously described (Thomas *et al.*, 2004). A FIG was established in order to begin the monitoring of nutrient flows and the development of integrated soil fertility management practices at the farm and household level with the objective of encouraging the production of high value income-generating production options. This approach builds on the reality that resource-poor farmers do not follow recommendations for inorganic fertilizer use either because they have little or no access to inputs or they cannot afford them. Their strategies are more aimed at risk aversion rather than maximizing production. In Khanasser, evidence of this is seen in the fact that farmers export sheep manure for sale rather than use it on their fields as a fertilizer or soil amendment (Figure 7).

Building on the fact that soil fertility management practices are more successful when developed jointly with farmers (Scoones & Toulmin, 1999), the project applied a participatory learning and action research (PLAR) approach to the existing soil fertility problems (Defoer & Budelman, 2000). Farmers, scientists and extension workers collaborated closely in order to improve farmers' soil fertility management firstly by analysing and diagnosing the diversity of the prevailing landscape, the current status of the soil fertility, and soil fertility management strategies. This was followed by planning, experimenting, and evaluating alternative and practical soil fertility management practices. The approach is based on farmers' experimentation in order to achieve a better use and higher returns of the resources available, and to provide management that is adapted to the diverse agro--ecosystems. The approach used visualising tools to improve farmers' understanding, stimulate the learning process, and to increase the farmers' ability to observe the dynamics of soil fertility on their farms. Innovative farmers were encouraged to share their experiences and convince other farmers of valid practices for soil fertility management.

In a series of meetings in Hwer Al-Hass village, located on the border of the Jebel Al Hass and the Khanasser Valley, the PLAR approach was introduced and explained to the farmers; a map of the community territory to visualise the boundaries of the village, locate different soil types, fertility patterns, management and land-use systems, was drawn by the farmers. A territory transect walk was conducted with the objective of analyzing the diversity of the landscape and identifying constraints and potential improvements in relation to farmers' soil management practices. Soil fertility management was analysed and the farms classified to assess farmers' understanding and judgment of appropriate soil fertility management. The last step in this diagnostic phase was drawing nutrient flow maps of the fields of the selected test farmers and conducting detailed surveys about the source and fate of the nutrient inputs and outputs. Quantification of the nutrients was followed by computing the nutrient flows in, out, and between the farm sub-systems using a computer model to give a clear picture about the effect of management practices on soil fertility, as well as assessing the nutrient gaps in the system where research and improvements could be directed.

At the household level, a study was conducted on the feasibility of growing tomatoes as a high value crop option using available nutrient resources such as sheep manure and the development of methods to efficiently use manure inputs and its interaction with water.

7. Results obtained

The results of farmer consultations showed that considerable knowledge exists in their village, and in their land and soil fertility patterns. Farmers have an efficient local classification system, which reflects the diversity in landscape, soils, land-use systems, and farmers' soil management practices. In addition, farmers also demonstrated a good ability to recognize both the constraints that hinder soil fertility management and the promising improvement practices (Table 1).

Farmers' indicators of a decline in soil fertility included poor plant growth, increased response to fertilization, weed and disease infestations. They attributed this fertility loss to mono-cropping, no fallowing, nutrient-mining, and an inadequate use of organic and inorganic inputs. It is interesting to note that farmers are aware of practices to improve soil fertility such as crop rotations, manure application, use of new cultivars and fallowing the land. However, they were also aware of

Land unit	Hamra	Safra	Araj	Jabalieh
Soil category	First	Second	Third	Fourth
Percent of area	55	15	20	10
Classification Criteria				
Soil colour	Dark brown	Light brown	Yellowish grey	Grey
Soil depth (m)	> 4	> 2	< 2	< 0.5
Soil quality	High	Good	Stony	Rocky
Management Practices				
Land-use system	Crop rotation	Crop rotation	Mono-cropping	Natural vegetation
Cultivated crops	Wheat, cumin, barley, lentil	Wheat, cumin, barley, lentil	Barley/olives	*Cachilla sp., Scorzonera papposa, Asphodelus microcarpus*
Fertilization	Sheep manure inorganic. N&P	Inorganic N	None	None
Tillage	Machinery	Machinery/feddan	None	None
Major constraints	Low moisture	Low moisture & low fertility	Shallow soils & stones	Large rocks, conflicts between farmers & herders
Potential improvements	Improved germplasm & management	Organic inputs	Land reclamation & organic inputs	Grazing management
Suitability	Crops & vegetables	Crops	Olives & forages	Medicinal plants & range land

Table 1. Farmers' local classification, description of soil types, management practices, constraints, potential improvements, and land-use suitability in Hwer Al-Hass Village.

the factors that hinder adoption of these improved management strategies. These included small land size (fallowing is not possible), financial constraints (inability to purchase inputs), the practice of selling manure rather than applying it to soil, and the lack of knowledge and incentives to conserve soil fertility (because of insecure land tenures).

The results of the diagnosis indicated that the farmers' favoured practices for soil fertility improvement were firstly, crop rotation (highest economic return from a small piece of land), and secondly, manure application (long-term effect on productivity and improved soil conditions). The third option was fallowing the land to conserve nutrients and soil moisture, and the last option was inorganic fertilizers regardless of the quick increase in productivity, ease of application and low labour demand.

Management Class	N_{inorg}	N_{org}	P_{inorg}	P_{org}	K_{inorg}	K_{org}
	Kg/ha					
Good soil fertility management[1]	11.50	109.0	5.20	44.00	0.00	81.00
Medium soil fertility management[2]	14.30	4.20	0.00	1.68	0.00	3.13
Poor soil fertility management[3]	12.10	0.00	2.64	0.00	0.00	0.00

Table 2. Use of inorganic and organic nutrient inputs as affected by the type of farmer's soil fertility management.

Criteria characterizing good, medium and poor soil fertility managers analysed in the Diagnostic Phase (Thomas et al., 2005)
[1] A good manager: crop rotation, manure, and knowledge
[2] A medium manager: only one from the above mentioned practices + inorganic fertilizer
[3] A poor manager: occasionally one from the most important practices

Nutrient Balance	N	P	K
	$Kg\ ha^{-1}$		
Good soil fertility management	46.20	42.20	56.70
Medium soil fertility management	-2.90	1.2	-7.00
Poor soil fertility management	-26.20	-2.60	-14.50

Table 3. Average nutrient balances as affected by the type of farmer's soil fertility management.

Nutrient Balance	N	P	K
	$Kg\ ha^{-1}$		
Cropping system/ with vegetables[1]	0.100	3.20	-4.70
Cropping system/ without vegetables[2]	-11.20	-1.70	-7.00
Barley/Fallow System	-11.90	1.50	-4.40

Table 4. Average nutrient balance as affected by the type of cropping system.

Nutrient balance calculated for the same cropping system including vegetables [1] as compared to the same cropping system excluding vegetables [2].

Fertilization plans were developed by farmers based on their available resources. Table 2 shows a classification of these practices based on combinations of available inorganic and organic nutrient sources.

The classification of good fertility management refers to those farmers using crop rotations and manures and that have good knowledge of soil fertility practices and balances, whereas a medium practice includes only one practice with the use of fertilisers, and a poor practice would only involve the occasional use of a key practice.

Analyses of these fertilization schemes results in estimations of nutrient balances, shown in Table 3.

Translating these options into the cropping systems used by farmers show that all cropping systems have some degree of negative nutrient balance (Table 4). The best practices in terms of nutrient balances include the incorporation of vegetable crops into the production system when only potassium is estimated to have a negative balance.

After concluding this, phase strategies for experimentation were discussed and planned by the farmers and researchers, and included:

- Introducing a forage legume, vetch (*Vicia sativa L*) to the village to develop a cereal-legume rotation instead of the usual cereal-cereal practice. The objectives of these experiments were to improve soil fertility (nitrogen-fixation), diversify production (security), provide a good quality fodder for livestock, select the best sowing time for the newly introduced forage legume, study the effect of using organic manure with the legume on the yield of cereals, and improve the farmer's income (selling seeds).

- Experiments to study new improved cereal cultivars wheat (*Triticum aestivum L.*) and barley (*Hordeum vulgare L.*). These experiments were conducted with the objectives of comparing emergence, growth, and maturity of improved cultivars to those used by the farmers, and to involve the farmers in the early stages of a breeding process in order to understand the farmers' preferences, the important criteria for selection, and the reasons for their selection, as well as to establish a participatory cereals breeding system in the village.

Prior to implementing the different experiments, soil samples were taken from the fields and analysed for organic matter, nutrient and water content. Data about production from the different fields in the previous season was collected and analytical data of nutrient contents of the produce were obtained. This enables a comparison and computation of the nutrient and water flows as a result of the farmers' management strategies to the introduced, as well as the improved management strategies as a result of introducing the PLAR approach. Throughout the growing season the farmers were visited by the PLAR team and their observations, comments and suggestions were discussed.

7.1 Evaluation Phase

7.1.1 Introduction of a legume into the rotation

After harvesting, soil and plant samples were taken for chemical analysis, and yield of different crops (grains, residue) were recorded to calculate the nutrient input and output. Results are pending further analyses. Preliminary results indicate that the average yield of barley after vetch was comparable or slightly higher to that obtained before incorporating the vetch (1.1 and 0.9 t/ha grain and straw and 1.05 and 0.9 t/ha, respectively) under medium and good fertility management conditions. The average yield of barley after vetch plus added animal manure (20 m^3) was only 50% (1.8 and 0.4 t/h grain and straw, respectively) that of barley with animal manure only, which has yielded 2.8 and 1.0 t/ha of grain and straw. This indicates that further research is needed on the effects of animal manure and vetch on cereal yields in the rotation. Soil analysis showed no differences in nitrogen concentrations in the soil before and after vetch as would be expected after one growing season. In general the participating farmers as well as over 50% of the households in the community, who have adopted the planting of vetch in rotation with barley and/or wheat, expressed their satisfaction with this strategy, because it restores or builds the soil fertility (which is a slow process) and at the same time provides the farmers with additional income by selling the vetch seed, i.e. it combines long-term soil fertility maintenance and build up and provides short term increases in income.

7.1.2 Improved barley and lentil varieties

Under medium soil fertility management classes, the average grain yield of the local barley variety was 1.05 ton/ha and average straw yield was 0.9 t/ha; under good fertility management, the yield was 2.8 t/ha grain and 1 t/ha straw as compared to the introduced Zanbaka and Tadmour varieties with an average grain yield of 0.9 t/ha and straw yield of 1 t/ha; and under good and medium fertility management, the yield was 0.62 t/ha grain and 0.8 t/ha straw. The farmers again opted for the local barley variety indicating that it is superior in terms of adaptability to their conditions, need less inputs, and the fact that the local variety yields more grain than the improved ones. However, one of the farmers expressed his interest in continuing to test with other new cultivars and comparing with the local barley variety.

The yields of both improved and local lentil varieties were severely affected by a phase of hot temperatures during the flowering stage. However, the improved lentil variety (Idlib 3) had a higher grain and straw yield of 0.4 and 1.3 t/ha, respectively, as compared to the local variety with 0.1 and 1 t/ha of grain and straw, respectively, under good fertility management conditions, and 0.04 and 0.6 t/ha of grain and straw, respectively, under medium fertility management. The farmers were enthusiastic for the new improved variety but suggested planting it again in the new cropping season in order to assess its full potential under their conditions.

Several meetings were held with the farmers to discuss the results. The preliminary evaluation showed that:

1. Farmers are pleased with the introduction of vetch into the rotation because of the good profits they could secure by selling the seeds and provision of feed to their livestock.

2. They are willing to include the vetch in the new season, rotating it with cereals in other fields, and they opted for early planting as being the best for their area.

3. Although the vetch was experimented only with the five test farmers, about sixteen farmers or more are willing to introduce vetch in their farms.

However, the farmers reported that they lacked the know-how on harvesting the crop and were faced by many difficulties and asked for solutions to be proposed for making the vetch harvesting a manageable task.

With regard to the cereal improved varieties, the farmers observed that for barley, the local variety usually used in the village proved to be superior to the improved cultivars and they opted to continue with the local variety. For the wheat varieties, the farmers selected early maturing new improved cultivars, which was promising because it can secure the yields; more often than not, the rains become scarce or completely stop before the end of the season resulting in drastic losses in yield. Also, several other farmers expressed their willingness to try the new early maturing wheat cultivars in the new season.

Concerning the intercropping experiments, the farmers agreed that it was too early to observe any effect but said there was no negative effect on the growing olives, i.e. the vetch did not cause any moisture stress or diseases to the trees (which was initially the primary concern of the farmers). A comparison of olive yield between the last and this season will be done when they harvest the crop. Of note is that they agreed to repeat the experiment in the new cropping season.

7.1.3 The use of sheep manure for tomatoes in home gardens

Experiments were conducted as part of an MSc thesis linked to Tishreen University in Lattakia, Syria, to determine the optimum use of water and nutrients from manures for irrigated tomatoes as a high value crop under controlled conditions. Sheep manure is currently exported from the valley to horticultural enterprises to the north of the region. This study attempted to encourage the use of these valuable nutrient resources as a soil amendment and fertilizer in home gardens. As tomatoes prefer a deep, loamy soil high in organic matter, home garden soils are an option as they are usually well-drained and receive full sun for most of the day.

The study involves both controlled experiments at ICARDA headquarters and field work in selected farmers' home gardens to:

- Determine the most appropriate rates and application times for using sheep manure with tomatoes in home gardens in rural societies.
- To observe the effect of water shortage on tomato growth and yield when manure is applied.
- To observe the effect of manure on physical and chemical properties of the soil.
- Determine the trades-off of manure uses – application versus direct sale to commercial horticultural producers.

In Table 5, the study stages of the field and pot experimental work conducted in 2006 and 2007 of tomatoes' cropping seasons are presented.

the same procedures (i.e., manure fertilization levels representing 7 rates (0; 10; 20; 40; 60; 80; and 100 t/ha as M_0; M_1; M_2; M_3; M_4; M_5; M_6, respectively) in addition to the optimum amount of NPK.

In this experiment, tomato biomass (shoots) was measured during the growth vegetative period. This process did not allow yield assessments. Nutrient uptake, available nutrients in plant and soil were also analysed prior to planting and after the maximum growth. Roots biomass was also determined. Quantities (g/pot) of vegetative biomass (shoots) increased with increasing the rates of sheep application up to 80 and 100, tons h-1, with the mineral fertilization producing the same result (Figure 9).

Year	Field experiment	Pot experiment in the greenhouse
Stage 1- 2006	The effect of different rates of animal manure on growth and yield of irrigated tomatoes	Field experiment repeated in the greenhouse
Stage 2- 2007	The effect of different rates of animal manure on growth and yield of irrigated tomatoes	The effect of water stress on growth, development, and fruiting of tomato plants amended with manure or mineral fertilization

Table 5. Study stages of the experimental work performed in field and in greenhouse during 2006- 2007 cropping seasons.

7.2 Results

7.2.1 Field experiments

The effect of different rates of animal manure on growth and yield of irrigated tomatoes in field experiments is shown in Figure 8 and indicates a positive effect of applications of sheep manure of up to 80 t ha^{-1} on yield. The highest yield (40.1 ton h^{-1}) was obtained with the application of 80 tons per hectare (i.e., 16.4 kg of sheep manure per $4m^2$ plot). The yield of mineral NPK fertilization (100 kg N + 50 kg P_2O_5 + 140 kg K_2O_5, per hectare) was 21.7 ton h^{-1}.

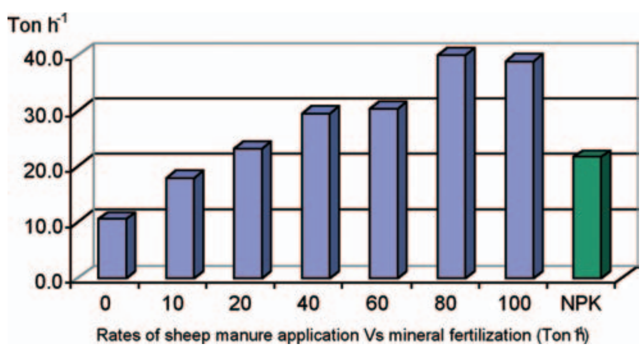

Figure 8. The effect of application of sheep manure vs mineral fertilization on the yield of tomatoes, results of the 2006 field experiment.

7.2.1.1 Pot experiment

To confirm the results obtained from the home garden fields, the experiment was repeated in glasshouses using

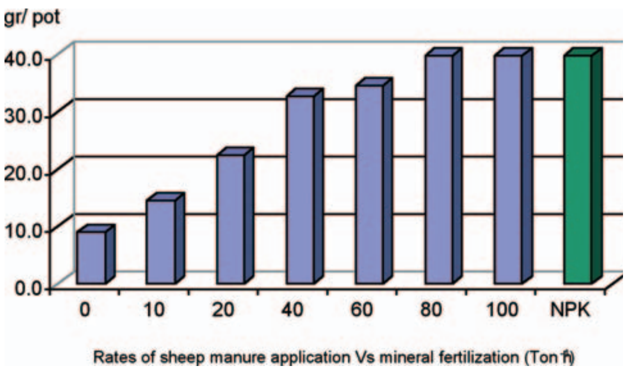

Figure 9. The effect of application of sheep manure vs mineral fertilization on the vegetative biomass (shoots), results of the 2006 pot experiment.

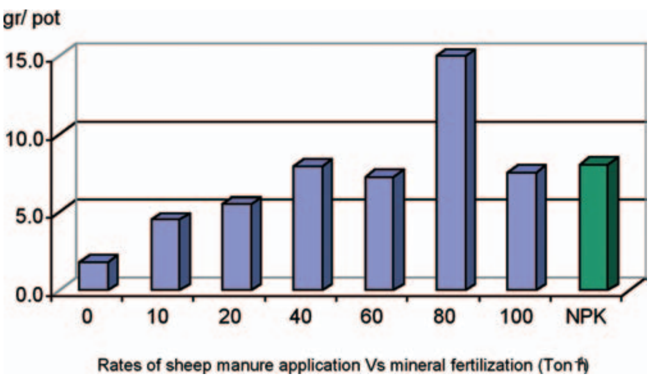

Figure 10. The effect of application of sheep manure vs mineral fertilization on the root biomass, results of the 2006 pot experiment.

Comparing the glasshouse and field results indicates that sheep manure may be a better option than mineral fertilizer even though under controlled conditions mineral fertilizer increases the vegetative biomass. The application of 80 tons h^{-1} of sheep manure gave both highest yields and root biomass (Figure 10).

8. Recommendations for sustainable dryland management

The findings of the research activities, the national seminars and farmer workshops when taken together and viewed as an integrated approach to natural resource management clearly indicate that solutions for marginal drylands cannot be just technical options but must focus on economic, environmental, social, institutional and policy aspects. This reinforces the findings from other studies in dry areas (MEA, 2005; Adeel *et al*., 2007; Thomas and Turkelboom, 2007).

An important aspect to consider is that few studies consider the multi-functionality of marginal dryland areas in terms of agricultural production, the social dimensions of reducing poverty and creating employment, the ability of drylands to provide environmental services through biodiversity conservation, soil and water conservation, recreation and aesthetic values, and the need to reverse or prevent land degradation.

Because of the complexity of the problems and opportunities of marginal drylands there is a need to improve the overall approach to solving the problems in a coherent and integrated way that must include the viewpoints of all stakeholders in well defined multi-stakeholder processes that can result in jointly prepared and agreed plans of action for the particular locality. This means bringing together the land-users, researchers and extension workers, civil society organizations, the private sector, and the policy or decision makers from government.

Devolution of decision making and planning to local level organizations is seen as a key to better co-management of these relatively vulnerable ecosystems and is essential for the successful introduction of improved technological options for agricultural production that do not compromise the environmental services that the marginal drylands provide.

Inevitably there will be a need for better ways to manage conflict resolution through negotiated action plans that avoid domination by power elites and include the voices of those that are usually excluded from such negotiations and planning. By focusing on the comparative advantages of marginal drylands the process will start on the positive aspects rather than the usual doomsday scenarios associated with desertification in the past.

9. National seminars

1. *Sustainable agricultural development for marginal dry areas: Khanasser Valley Integrated Research Site* (co-sponsored by BMZ, Germany) was held 12–13 January, 2005 at ICARDA headquarters, Aleppo, Syria and was attended by 132 participants.
   Main outcomes: Improved understanding between stakeholders on development and natural resource management issues in marginal zones of Syria; a list of technological options for marginal zones with identified target group and indications of advantages and disadvantages of the options; better understanding amongst stakeholders on how they can contribute and stimulate sustainable development; summary of discussions to be presented to policy makers.

2. *Sustainable rural development strategies for dry marginal areas* was held 6 July, 2005, Damascus, Syria and was attended by 50 participants.
   Main outcomes: Combating desertification needs to be tackled using an integrated multi-sector approach; marginal and dry areas are distinct regions and need support; sustainable solutions will only be found by research and development through consultation and coordination amongst all stakeholders; promising options for the marginal dry areas are available; long-term monitoring and evaluation are required.

3. *Implications of the Khanasser Valley Integrated research site for other areas in Syria* was held 22 January, 2006, Offices of the State Planning Commission for Syria, Damascus, Syria and was attended by 40 participants from research organizations and government ministries of agriculture, water and irrigation, rural development including the Head of the State Planning Commission,
   Main outcome: Agreement to replicate the Khanasser experience elsewhere in Syria, and the joint development of a proposal for international funding.

4. Establishment of the Jabbul Agro-ecosystem Steering Committee, several meetings were held over a period between May 2005 and July 2007 with 20–50 participants at each meeting. Various participants from over twenty local government and non-governmental institutions including the Deputy Minister of the Environments and the Governor of Aleppo, representatives of the Ministries of Agriculture, Irrigation, Environment, Higher Education, Chambers of Agriculture and Industries, Municipal Council of Aleppo, farmers and farmer unions, researchers and students.
   Main outcomes: Four Task Forces to consider biodiversity and conservation, water management, pollution control and enhancement of livelihoods. A total of 33 recommendations and a framework for action were agreed.

10. Research institutions and team composition

10.1 Research institution

International Centre for Agricultural Research in the Dry Areas (ICARDA)
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Aleppo
Syria

10.2 Team composition

Team leader: Dr. Richard Thomas, soil, water and nutrient management specialist.

Team members

Dr. Francis Turkelboom, soil and water conservation specialist.
Dr. Adrian Bruggeman, hydrologist.
Dr. Zuhair Masri, soil conservation specialist.
Dr. Robert La Rovere, socio-economist.
Dr. Aden Aw-Hassan, socio-economist.
Dr. Hanadi El-Dessougi, post-doctoral fellow soil nutrients.
Dr. Elco Luijendijk, post-graduate student, hydrologist.
Mr. Sami Wahiba, MSc undergraduate student.
General Commission for Scientific Agricultural Research (GCSAR).
Ministry of Agriculture and Agrarian Reform, Syria.
Professor Giath Alloush, University of Tishreen, Lattakia, Syria.
Dr. Mohamed Al Oudat, plant ecologist.
Dr. Fares Asfary, soil fertility specialist.
Syrian Atomic Energy Commission

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8

Zeuss-Koutine Watershed

Tunisia

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Introduction

This report summarizes the scientific activities undertaken at the Tunisian project site (Watershed of Zeuss Koutine), as part of the implementation of the UNESCO-UNU-ICARDA joint 'Sustainable management of marginal Drylands' (SUMAMAD) project during the period covering 2003–2007.

As the project was designed to build on previous or ongoing projects (such as WAHIA, Jeffara, MEDRATE), the team concentrated first on the review of the available outputs. Additional investigations were later carried out mainly in relation to the income-generating activities, soil and water conservation, social development, and natural vegetation and rangeland economics. In addition, outreach activities (such as training and seminars) also took place.

1. Main dryland challenges at the project site

In Tunisia, drought and desertification particularly affects arid and semi-arid regions and are characterized by unfavorable climatological and hydrological conditions (FAO, 1986). Low and erratic rainfall results in frequent periods of serious drought alternating with periods of floods causing major damage and soil erosion (Floret and Pontanier, 1982).

For the last two decades the Tunisian government has engaged a vast program for the conservation and mobilization of natural resources: national strategies for soil and water conservation, forest and rangelands rehabilitation, water resources (Minis. Agri., 1990*a*, 1990*b*, 1990*c*). In the Tunisian Jeffara, which encompasses our study area, the traditional production systems is such that it concentrates production means on limited areas, with an extensive exploitation of pastoral resources in the majority of the zone. However, during the last forty years, a rapid and remarkable evolution of these production systems has taken place, and natural resource exploitation has increased with subsequent exploitation by drilling of groundwater aquifers for the development of irrigated crops and industry, as well as the rapid expansion of fruit tree orchards at the expense of natural grazing lands following the privatization of collective tribal lands. In this context, the spatial complementarily of the agrarian system has disappeared and been replaced with other interconnected and neighbouring production systems. Those systems are marked by competition for access to natural resources, especially for land ownership and water use (Genin *et al*., 2006). Important activities for soil and water conservation and rangelands rehabilitation have been implemented whose immediate effects are visible, but their efficiency on the short and long-terms has not yet been assessed and evaluated in detail.

In line with the UNCCD National Action Program in which desertification is considered a development problem,

SUMAMAD	Tunisia
Assessment of the current status of integration	Identify the interactions between the evolution of resource utilization methods, production systems and the land ownership.
Identification of practices for sustainable soil and water conservation	Assess and validate the various old and new practices for soil and water management and for combating desertification,
Identification of training needs	Provide suitable training of IRA's team and its partners in the various themes embedded by the project.
Identification of one to two income-generating activities	To identify alternative income-generating activities for improving the livelihood of the local population while alleviating the pressure on the natural resources.

Table 1. The SUMAMAD objectives for Zeuss–Koutine study site.

the search for alternative income-generating activities of the affected populations is becoming a priority subject whose objective is both to alleviate the pressure on the natural vegetation and poverty (MEDD, 2006).

Within this framework, the SUMAMAD objectives applied in the Tunisian research site, are given in Table 1 above.

2. Environmental characteristics of the study site

2.1 Location

The Watershed of Zeuss-Koutine study site (SS) is situated to the north of the city of Médenine in the south eastern region of Tunisia. It stretches from the south-west of the Matmata mountains near Béni Khdache and Toujane, across the Jeffara plain and into the Gulf of Gabès, terminating in the saline depression (*sebkha*) of Oum Zessar. It is bordered at the north by the Segai plain and the town of Mareth (Figure 1).

Figure 1. Location map of the study site and the intervention areas of the collaborating NGOs.

2.2 Climate

By virtue of its position, the climate in the study site is of the Mediterranean type. The coldest months are December, January and February with occasional freezing (up to -3°C). June through to August is the warmest period of the year during which the temperature can reach as high as 48°C (in the shade). The temperature in the SS is affected by altitude and its proximity to the sea.

Having an arid climate, the rainfall in the SS is characterized by low averages, high irregularity (both in time and space) and torrentially. It receives between 150 and 240 mm of rainfall per year, with an average of thirty rainy days (Derouiche, 1997). The prevailing winds affecting the plain are, in the winter, the cool and humid eastern/northeastern winds, and in the summer, the hot and dry

Parameters	Wadi Oum Zessar	Wadi Zeuss	Wadi Zigzaou
Area	367 km^2	219 km^2	195 km^2
Perimeter	118 km	61 km	95 km
Compacity Index of Gravilus	1.72	1.15	1.9
Maxi. altitude	715 m	302 m	632 m
Mini. altitude	0 m	0 m	0 m
Global slope index	11.11 m/km	13.94 m/km	8.17 m/km
Equivalent length	51.74 km	18.64 km	42.82 km
Equivalent width	7.1 km	11.74 km	4.55 km
Av. runoff vol. (Fersi, 1980)	4.70 Mm^3/year	1.26 Mm^3/year	2.78 Mm^3/year

Table 2. Hydrological characteristics of the SS.

southeastern winds called *Chhili* or *Guebli*. With high temperature and low rainfall, the potential evapotranspiration (ETP) is very high, for example, it can reach 1,321 mm in Médenine. The climatic water balance is almost negative throughout the year.

2.3 Hydrology

The main hydrological characteristics of the SS are given in Table 2.

2.4 Geology and soils

The SS is situated on the edge of two major geological landscapes: the Djebel Matmata and the Jeffara. Djebel Matmata crosses the region from the northwest to the southeast where the range becomes less massive and is cut into a number of hills with an average altitude of 400 m, whereas in the north altitudes reach more than 600 m.

The Jeffara consists of the plain originating north of Gabès and stretches in a NW-SE direction forming the large area between the Mediterranean (Gulf of Gabès) and the Matmata mountains. At its highest point, it reaches an altitude of 100 m, and terminates in the internal (sebkhas) or coastal (lagunes) depressions.

The geological formations consist of alternating continental and marine origin. The oldest submerging layers are represented by marine, superior Permian, and the most recent layers correspond to the recent Quaternary. In between, strata of different ages appear, which is generally declining in a northward direction. The main soil groupings are regosols and lithosols; erosion rapidly exceeds soil forming processes, they have little depth and lay on soft rock (regosols) or on hard rock (lithosols).

2.5 Hydrogeology

The underground water resources could be subdivided into two main groups: the deep water tables, and the surface water tables.

2.5.1 Deep aquifers

The most important one is the Zeuss-Koutine aquifer. It is situated between the mountains in the southwest, the submerging Jurassic of the Tadjeras in the south-east and the Médenine fault in the north east, and consists of Jurassic age layers. It is sustained by infiltrating water from the Zigzaou, Zeus,and Oum Zessar wadis as well as the CI (Continental Intercalaire). Renewable resources are estimated at 350 l/s with a salinity ranging from 1.5 to 5 g/l. The depth varies between 170 and 680 m.

The second aquifer is the Grès du Trias. It extends from Harboub in the south, the zone of Médenine and Metameur in the east, Wadi Hallouf in the north, and the Dahar fault in the west. Supplied by the wadis of El Ababsa plain, it is contained in the upper Triassic formations. Salinity ranges from 0.9 g/l at El Megarine, and 1.5 at Harboub. Actual exploitation is around 130 l/s, with renewable resources estimated at 80 l/s. The average depth is about 150 m.

2.5.2 Shallow aquifers

They are found within a depth of less than 50 m. They are mostly generated by the subsurface underflow of the big wadis.

2.6 Vegetation

The vegetation found on the plains and the foot of the mountains can physiognomically be labeled as typical of steppes, except for the few 'islands' in the valleys and depressions. Wadi beds and watercourses are rich in species of different biogeographical origins. Another group of 'botanical islands' include the number of sites of degraded forest on the hills near Beni Khdache (MEAT, 1998).

2.7 Water harvesting and sand dune stabilization techniques

A wide variety of water harvesting techniques is found in the study watershed. In fact, the hydraulic history of this watershed is very ancient (Carton, 1888) witnessed by the remnants of a small retention dam supposedly built in the Roman era near the village of Koutine and the abandoned terraces on the mountains of wadi Nagab, in addition to numerous flood spreading structures found in henchir Zitoun, henchir rmadi etc. (Ouessar *et al*., 2002; Ben Khehia *et al*., 2002). The main encountered systems are *jessour* on the mountain ranges, *tabias* on the foothills and piedmont areas, and cisterns and groundwater recharge gabion structures in the wadis courses.

In the downstream area, where the wind is very active, preventive and curative techniques are used (Khatteli, 1996).

3. Socio-demographic characteristics of the study site

The SS covers the territory of 13 *imadas* (the smallest administrative unit in Tunisia) belonging to four delegations: Béni Khédèche (3), Médenine North (3), Sidi Makhlouf (4), and Mareth (3). The population is estimated at more than 62,000 inhabitants comprising almost 10,000 households (Jeffara, 2003*b*). The SS is predominantly rural where five ethnic groups reside. Traditionally, economic activities are based on livestock and rainfed farming. However, in response to the harsh environment, a multi-source income-generation strategy was developed a long time ago. In addition to the former activities, the people adapt themselves to any economic and geopolitic reality; migration (internal and external), trade, intensive farming (irrigation and so on) (Mzabi, 1988).

Agricultural production operates within a variety of farming systems from the upstream to downstream areas of the SS, and is marked by their diversity. These systems are essentially distinguished by:

- a non regular agricultural production that varies from one year to another depending on the rainfall regime;
- the development of arboriculture and the extension of newly cultivated fields at the expense of rangelands;
- gradual transformation of the livestock husbandry systems from the extensive mode, which is highly dependent on the natural grazing lands, to the intensive mode;
- development of irrigated agriculture that exploits the shallow and deep aquifers of the region;
- the predominance of olive trees (almost 90 %), and the development of episodic cereals.

Research undertaken in the study area revealed that the main farming systems are:

- *Jessour* systems.
- Irrigated perimeter systems with two subsystems: the

subsystem of private irrigated perimeters, and the subsystem of public irrigated perimeters.

- Olive tree systems.
- Multicrop systems, breeding with two subsystems: the subsystem of the marginal agriculture, and the subsystem of the agro--breeders.

4. Conservation of natural resources, community development and scientific information

South-eastern Tunisia is dry. On average, the mountain and coastal areas receive more than 200 mm/year of rainfall whereas it varies between 100 and 150 mm/year in the remaining parts. It results in irregular and ineffective runoff (Bonvallot, 1979). However, the few intensive rainfall storms generate concentrated flushing floods at the level of wadi beds (Fersi, 1980).

4.1 Precipitation

Localized in Tunisian arid areas, the watershed of Zeuss-Koutine receives less than 200 mm/year with approximately thirty rainfall days. Rainfall is torrential and characterized by low averages and spatial and temporal variations. The months of November, October, December, January and February are the wettest while the summer season is almost dry.

As regards the monthly variability of precipitation, we note that outside the dry summer period, where the variability is about 300 %, extreme values of more than 600 % can be reached. This value ranges between 100 and 150 % for the remainder of the year. At the annual level, the coefficient of variation of rainfall is around 56 %. The relationship between absolute maximum and absolute minimum rainfall varies from 8.6 in Béni Khédache to 15 in Médenine. Drought is becoming a more recurrent phenomenon especially in the dry areas of the country where severe damage, especially of fruit trees (olive), is a result. In this framework, it was judged useful to undertake a study on drought and rainfall variability in our study area (Dhaou, 2003).

The weather station at Médenine was chosen as an application case as it has relatively long monthly rainfall records of more than 90 years (96 years of complete observations). For the other stations, analysis was limited to a period of 24 years observation, except for the stations at Sidi Makhlouf and El Gourine (18 and 10 years of observations, respectively). Several methods and indices were used to characterize and estimate the intensity of drought at the level of the rainfall gauge stations: Index of deviation to average, Index of rainfall, frequency analysis, index of the number of standard deviations, and persistence of drought.

The analysis of rainfall records through drought indices at the weather station in Médenine shows that drought is a recurrent phenomenon. The first method gives a percentage of 60 % of dry years whereas the frequency analysis reduces it to 34 %. Moreover, the frequency of appearance of successive dry years is relatively high (51.5 % of cycles have dry years of two or three consecutive years). Moreover, during the previous decade and more, particularly during the beginning of this century (1999–2002), exceptional rainfall deficits were recorded of up to 152.25 mm at Ksar Jdid for example. They induced negative impacts on the development and growth of fruit trees resulting in partial or total withering of large parts of the fruit tree groves in the area and particularly with olives (Dhaou, 2003).

4.2 Hydrology

The drainage area of the study site comprises five main watersheds: Zeuss, Oum Zessar, Zigzaou, Mourra and Sid Makhlouf. Based on runoff measurements undertaken in the arid regions of Tunisia, Fersi (1985) developed a simple method for estimating the average annual runoff. The application of Fersi's formula to the sub-watersheds gives 11.21 Mm^3/year.

4.3 Groundwater

The scarcity of rainfall in southern Tunisia is relatively compensated by its groundwater resources (Mzabi, 1988). The various hydrogeologic studies carried out in the region showed that the Zeuss-Koutine area is rich in aquifer formations, which can be subdivided into two categories: shallow and deep aquifers (Ben Baccar, 1982; Gaubi, 1995; Yahyaoui, 2001*a*).

The shallow aquifers are distinguished according to their geographical position. Thus, five aquifers were identified of which the most important are Jorf and Metameur. These aquifers are, for the most part, saline (Labiadh, 2003; Ouessar *et al*., 2003).

The characteristics of the various deep aquifers in the study were summarized by Labiadh (2003). Except for the Jurassic aquifer of Beni Khédache, the pumping rate of the various aquifers is very high, as well as its salinity.

4.4 Soils

Because of the absence of a soil map at a suitable scale, the realization of a new soil map was judged necessary. Two scenes of Spot XS image (KJ 67283 of the 26/05/98 and KJ 68283 of 31/05/98) were the first to be used, and enabled, by photo-interpretation, the production of homogeneous units. Subsequently, thirty-one soil profiles were taken and described of which eighteen were analysed. Following the interpretation of these data, and according to French soil classification (CPCS), a soil map was elaborated. The soils of the catchment area of Zeuss-Koutine have developed on a calcareous substratum in the upstream area, and gypsum or gypsum to calcareous in the downstream area. The soil horizons are generally shallow, stony and unstructured with sandy to fine sandy texture. Five main classes have been identified (Taamallah, 2003) and are described below:

- *Course mineral soils (eroded)* (lithosols) made mainly of dolomites, limestone outcroppings and stony regs. They are located in the upstream area (mountains and hills). They cover 20% of the study area.
- *Slow-evolving soils (Fluvisols)* occupy a relatively reduced area and are found in the plain and downstream areas. They represent 13%.
- *Calcimagnesic soils* represented by rendzinas on calcareous or gypsum crusting, or on the miopliocene. They cover an important area on the upstream and piedmont parts (35%).
- *Brown isohumictruncated calcareous soils* are not very deep soils overlaying on the dismantled calcareous crust of villafranchian and sometimes covered by a shallow (few centimeters thick) of wind deposits. They cover 20% of the region.
- *Halomorphic and hydromorphic soils* (solonchak and solonetz) are encountered at the level of depressions (*sebkhas* and *garaas*) on the coastal areas. They are characterized by very high salinity (12%).

4.5 Natural vegetation types and their dynamics

The study area is characterized by a high diversity of vegetation types. They are linked to several ecological groups whose major part is mostly attributed by soil type (Ouled Belgacem & Genin, 2003 (associations of *Anarrhinum brevifolium* and *Zygophyllum album*, of *Artemisia herba-alba* and *Hammada scoparia* and so on) but also human pressure (association of *Pituranthos tortuosus* and *Haplophyllum vermiculare*, facies of *Pituranthos tortuosus* and *Artemisia campestris*). This could be explained by the important role of soil and human activities in the determination of plant cover in these arid regions of Tunisia. Climatic factors, which are not very variable, do not play an important role in the region's plant diversity. The elaboration of the vegetation map has been preceded by the analysis and treatment of the field data collected from 169 ecological sites. The dominant vegetation types characterizing the study area, as determined by the Corresponding Factorial Analysis (CFA) and the Ascendant Hierarchical Classification (AHC), are as follows:

- Association of *Anarrhinum brevifolium* and *Zygophyllum album*, facies type,
- Association of *Stipagro-stis pungens* and *Salsola vermiculata subsp. Villosa*, facies type (Le Houérou, 1959),
- Association of Juniperus phoenicea and Rosmarinus officinalis (Le Houérou, 1959),
- Association of *Artemisia herba-alba* and *Hammada scoparia*, facies type,
- Association of *Artemisia campestris* and *Thymus capitatus* (Le Floc'h, 1973), facies type ;
- Association of *Pituranthos tortuosus* and *Haplophyllum vermiculare* (Le Houérou, 1959),
- Association of *Ziziphus lotus* and *Retama raetam*, facies type (Le Houérou, 1959),
- Association of *Ziziphus lotus* and *Nitraria retusa*, facies type (Le Houérou, 1959),
- Association of *Rhanterium suaveolens* and *Artemisia campestris*, facies type (Le Houérou, 1969)
- Association of *Stipa tenacissima* and *Rosmarinus officinalis*, facies type (Le Houérou, 1959),
- Association of *Genista microcephala var. tripolitana* and *Teucrium alopecurus*, facies type (Le Houérou, 1959),
- Association of *Nitraria retusa*, *Suaeda mollis* and *Salsola sieberi var. vesceritensis* (Le Houérou, 1959),
- Association of *Limoniastrum guyonianum* and *Nitraria retusa* (Braun-Blanquet, 1949),
- Association of *Frankenia thymefolia, Limoniastrum pruinosum* and *Limoniastrum guyonianum* (Waechter, 1980),
- Association of *Arthrocnemum macrostachyum* and *Nitraria retusa* (Novikoff, 1965).

This analysis allowed us not only to locate the main vegetation types, which were determined earlier, but also to identify new degraded facies of *Helianthemum lippii var. intricatum* of the *Anarrhinum brevifolium* and *Zygophyllum album* association.

The determination of these different vegetation types and the spacialization of the field data with reference to GIS, helped formulate the vegetation map of 2001 (Hanafi & Ouled Belgacem, 2006). A high diversity of vegetation types was found due to biotic factors (soil water availability, physico-chemical characteristics of soils) as well as to abiotic factors (topography, human activities). According to the upstream-downstream sequence we can distinguish relics of *Juniperus phoenicea* and *Rosmarinus officinalis* evergreen garrigue at higher altitudes in calcareous mountains followed by the *Stipa tenacissima* steppe, which dominates the calcareous crust mountains. When degraded, this steppe is replaced by the *Artemisia herba-alba* and *Hammada scoparia* steppe with its *Gymnocarpos decander* facies. In the piedmont of gypseous crusts, *Anarrhinum brevifolium* and *Zygophyllum album* is mostly degraded and very often replaces *Astragalus armatus*, *Atractylis serratuloides* or *Lygeum spartum* steppe. The lowlands are very often covered by steppes of *Ziziphus lotus*, but in 'stream beds' the *Artemisia campestris* and *Thymus capitatus* steppe often dominate. The sandy valleys to the south-west of the study area are mainly dominated by much degraded *Rhanterium suaveolens* steppe, which generally has been replaced by different deterioration communities of *Astragalus armatus* or *Lygeum spartum* or its abandoned fallow lands with *Artemisia campestris* and *Pituranthos tortuosus*. Toward the downstream and in the salty closed depressions (sebkhas), the plant cover is generally dominated by halophytes such as *Nitraria retusa, Suaeda mollis* and *Limoniastrum guyonianum*.

In order to better understand the human pressure on the environment, the dynamics of each vegetation type is studied by comparison with the use of GIS tools, data and maps of the two different situations (1976); an important extension of the cropping area especially in the sites where the topography is favourable for sediment and runoff collection. In fact, the data provided by GIS showed 1) an important decrease of the pure steppe area of about 13,700 ha (36%) between 1972 and 2001 in favor of the cropping area, which increased by about 200%, and 2) an active dynamic of the different vegetation types in a relatively short period (30 years). This dynamic is linked to anthropogenic factors (agricultural development, grazing) favoured by endogenous conditions (physico-chemical characteristics of soils, stock of seeds in the soils). The important extension of crops at the expense of high range value vegetation types covering the good soils (i.e. steppes of lowlands) was also shown. These vegetation types are often replaced by other plant communities dominated by spiny species of low range values (i.e. steppe of *Astragalus armatus* replacing steppes of *Rhanterium suaveolens*).

4.6 Socio-economic characterization

4.6.1 Socio-demographic characteristics

The demographic evolution of the population of the studied zone in the Jeffara reflects the encountered trends in southern Tunisian. In fact it falls within the general trend of the population at the country level: lower adult mortality attributable to longevity, and especially infant mortality, reduction of fecundity i.e. a drop in the number of children per household, and an increase in marital age. This evolution results in a doubling of the population of the South since 1966 (664,000 inhabitants in 1966 to 1,364,083 in 1994) and by the increase in urbanization supported by the diversification of economic activities as well as government intervention (the urban population of the South represents 15.9 % of the total urban population of the country compared to 9.4% in 1956). On the other hand, there was a decrease in terms of the total population of the country of Southern Tunisia (from 16.6 % in 1936 to 14.9 % in 1984). This decrease is due to international migration to Europe especially between 1960 and 1985. The proportion is around 16 % today because of the decrease of the international migration in favor of the province of Médenine. In addition, the south of Tunisia is characterized by higher fertility than the national average especially in the last decade (in 1994: 3.51; Tunisia: 2.9; in 1998: 2.6; Tunisia: 2.3). The province of Médenine is in a distinct situation compared to other provinces of the South. Despite the migratory movements to Djerba and Zarzis due to the expansion of tourist resorts, especially during the period 1975–1984, the population of the study zone (the watershed of Zeuss-Koutine) doubled between 1975 and 1994. This evolution was marked by migratory movements, especially during the period 1975–1984. The rural area was subject to a vast reorganization of farming activities. In fact, the ratio between the urban and the rural population doubled. The higher growth rates were recorded in the counties of the plains (North Médenine, South Médenine and Mareth-Arram) rather than among the population of mountain dwellers (Béni Kedache).

The average number of members per household in the study zone is 6.41; it is higher than that observed during the 1994 census in Médenine province (5.48) and in Tunisia (5.16). The households are larger (7.18) in the mountain areas than in the plain (6.16). The household core family structure is expressed by the ratio of the average number of children per head of household to the number of children still residing with the head of household; this indicates the degree of cohabitation between the various generations (upholding the traditional patriarchal system), the importance of fertility per head of household, and the number of children that remain under charge by the household. From the upstream to downstream of the study zone, the family core trends decrease from 1.46 to 1.26 indicating a higher degree of cohabitation in the mountain-piedmont areas than in the plains. In the same way, the families have more children in the upstream zone (5.03) than in the plains (4.68), and the number of children still living with the household follows the same trend (3.37 against 2.39) (Sghaier *et al*., 2003*b*).

These characteristics tend to confirm not only resistance to modern reproductive behaviours (reduction in the number of children), but also the maintenance of the large traditional family of these zones (in mountains and piedmonts), which are still under or only recently urbanized and equipped. In the plains, the proximity to cities (infrastructure, living standards, employment opportunities) lead to family behaviours which are similar to the observed trends at national level: reduction of fecundity, mononuclear family, reduction of cohabitation between generations. Compared to rural Tunisia, the average age of head of household is rather high (53 years). It is higher in upstream regions than in downstream regions (56.2 years in Béni Khedache and 50.8 in Mareth) confirming the maintenance of a more long-lived patriarchal authority within the structure of larger families in mountain and piedmont zones than in the plains (Sghaier *et al*., 2003*b*). The average age of the population in the study zone is 3 years more than observed in Médenine province and rural Tunisia (28.8 years with the census in 2002, 25.8 with the census of 1994). This difference is due to the relative low number of young children mainly 0–4 year age group, and emigration (Sghaier *et al*., 2003*b*).

The importance of the agricultural sector in Médenine province can be determined by that part of the annual income generated by this sector, which in 1994 reached 116 million dinars (~ 94 million USD), as well as the percentage of labor attributed to this sector, which at the same date reached 19% of the active population. However, this rate is in continuous regression passing from 26.6% in 1989 to 21.6% in 1994 (MEAT, 1998). This sector is confronted by a number of problems such as desertification, water scarcity, and the marginalization of pasture lands. The productivity of certain cropping species remains low and variable and not very competitive. The agricultural production is, in all cases, highly dependent on climatic conditions. Nevertheless, agriculture always represents an important sector with twofold dimensions both economic and socio-cultural. On the one hand, it represents a source of subsistence, production of wealth, and risk management, and on the other hand, a cultural and patrimony reference.

The traditional production systems combined both the concentration of the production inputs on limited areas and the extensive exploitation of pastoral resources. During the last forty years, the production systems evolved rapidly and were marked by the exploitation of the natural resources. By drilling into the groundwater resources, water availability increased and was used to extend the irrigated fields and agro--food industries as well as for the expansion of arboriculture on coastal areas due to land property transfers (land privatization). In this context, the spatial agrarian complementary systems disappeared and were replaced by inter-connected production systems whose dynamic is expressed by the competition for access to natural resources and especially water (Guillaume *et al*., 2003).

The farming systems are marked by their diversity from the upstream to downstream areas. These systems are essentially distinguished by: 1) a non regular agricultural production that varies from one year to another depending on the rainfall regime; 2) the development of fruit tree orchards and the extension of newly cultivated fields at the expense of rangelands; 3) the gradual transformation of livestock husbandry systems from the extensive mode, highly dependent on the natural grazing lands, to the intensive mode; 4) the development of irrigated agriculture exploiting the shallow and deep groundwater aquifers of the region; and, 5) the predominance of the olive trees (almost 90 %) and the development of episodic cereals. The main farming systems encountered are:

System of *jessour*, system of irrigated perimeters, system of olive trees, and system of multicrop agro--breeding.

Arboriculture represents the main agricultural activity in the area. The olive tree is the main species cultivated in row cropping with other trees (fig, almond) on the terraces of the water harvesting structures. The olive-growing production dominates the quasi-totality of the agricultural production in the various geophysical zones of the watershed area amounting to 77% in the mountain (jebel) area and 55% in the central plain. The cereals occupy second place with a light concentration in the zone of piedmont at the rate of 26% (Sghaier *et al*., 2003*a*). Breeding, considered a traditional activity inherited from the past during the nomadic era, still occupies an important place in the economy of the study zone and notably the family income (27% of the agricultural income). Breeding concerns primarily small ruminants and camels. The pasture lands, which represent the main support of the breeding sector, cover 187,507 ha in the Zeuss-Koutine regions i.e. 3% of the national rangelands. According to the livestock census taken in 2000, livestock comprises 98,800 heads of sheep, 60,400 heads of goats, and 1,150 heads of camels. On average the herd is made up of 8.5 sheep, 4.59 goats and 1.95 camels. This number varies largely from one site to another (Sghaier *et al*., 2003*a*).

4.6.2 Land tenure

Land tenure in Tunisia, which began to be modified by the beginning of the colonization period, has been heavily subjected to the rapid changes during recent decades. Up to Independence, most of the land in the study zone was collective. However, following the promulgation of many laws, the process of privatization accelerated which encouraged people to transform the rangelands into cropping fields, and today most of the land is under private ownership. This resulted in the expansion of olive growing orchards at the expense of grazing lands. The evolution of land tenure is linked to the attribution of private ownership from collective lands. The collective status of the land has undergone constant change covering three main periods (1901–1964, 1964–1974 and 1974–1998). The area of collective lands decreased from 99,150 ha in 1901 to 19,680 ha in 1998, i.e. a reduction of 80 %, and 86 % has been attributed to private owners whereas the remaining 14% are proclaimed as ranges within forest lands. During the period 1964–1974, private lands doubled whereas it only increased by 19% between 1974 and 1998 due to difficulties in procedural attribution as well as the difficulties encountered at the level of some communities i.e. tribal conflicts. The current land tenure situation of the study zone is characterized by the prevalence of small-sized properties; 50 % of the farms have a maximum area of 5 ha (Sghaier *et al*., 2003).

5. Practices implemented for soil and water conservation

5.1 Inventory, description and achievements

Two major types of techniques to combat desertification were applied: water harvesting techniques (WHT) and sand dune fixation.

A wide variety of water harvesting techniques is found in the study area. In fact, the hydraulic history of this watershed is very ancient (Carton, 1888) witnessed by the remnants of a small retention dam supposedly built in the Roman era near the village of Koutine, and the abandoned terraces on the mountains of wadi Nagab, in addition to numerous flood spreading structures (henchir Zitoun, henchir rmadi and so on) (Ouessar *et al*., 2002; Ben Khehia *et al*., 2002; Ben Mechlia & Ouessar, 2004). The main encountered systems are: jessour on the mountain ranges, tabias on the foothills and piedmont areas, cisterns, and groundwater recharge gabion structures in the wadis courses. Within the framework of the national strategy for soil and water conservation, between 1990 and 2000, huge undertakings have been realized. In fact they include: the treatment of approximately 6,500 ha in jessour, tabias, the installation of more than 175 units for groundwater recharge and flood spreading, the installation of more than 10 recharge wells, and the safeguard and consolidation of more than 8,500 ha.

The sand dune fixation techniques include:

Mechanic fixation:
This is the first step in sand fixation. It consists of creating obstacles against the prevailing winds in order to decrease its speed and to enhance sand accumulation in the form of artificial dunes. Two materials have been used to achieve this: fibrocement plaques, which were gradually replaced by dry date palms (Khatteli, 1996).

Squaring:
This technique consists of installing a network of palisades which are laid out in a chessboard pattern (Khatteli, 1996).

Afforestation and pastoral improvement:
This operation consists of fixing the moving sand dunes by plantations once the mechanical stabilization is complete. Various forest species are used for combating sand encroachment in the study area, and are divided into two groups (Mekrazi, 2003):
- Introduced species: *Eucalyptus, Acacia cyanophylla, Acacia ligulata, Prosopis will juliflora, Parkinsonia, Pine of alep, Acacia horrida, Acacia tortillis, Acacia cyclopis, Casuarina*.
- Local species: *Calligomaum azel, Lycium arabicuim, Atripex halimus, Tamarix*.

The Office of Livestock Breeding and Pastures (OEP) practices rangeland enclosures and pastoral improvement through the plantation of fodder shrubs at the level of private lands (Ouled Belgacem & Genin, 2003). The area is enclosed for 3 to 5 years, which allows the vegetation to regenerate naturally without any intervention. Pastoral improvements are carried out by planting fodder shrubs such as *Atriplex halimus, Atriplex nummularia, Rhanterium suaveolens, Periploca laevigata*. In the Jeffara region, the afforestation programs, which started in the colonial period, along the Tripolitan road in particular, were continued during the 1960s by the forest services who were aiming to protect the agglomerations and infrastructures from sand encroachment. These plantations were installed on state owned lands or collective rangelands subject to the forestry regime. The OEP duplicated the same practices on private rangelands by installing enclosures or fodder shrub plantations instead of providing owners with subsidies for three year periods, depending on the success of the operation (Mekrazi, 2004). Almost 25 sites have been identified in the study area where the forest services or the OEP have intervened.

6. Income-generating activities

6.1 Introduction

The economic activity in the Tunisian rural areas is marked by diversification and economic complementarity and we often speak about 'multi-activity' (Sghaier *et al*., 2003*b*). This multi-activity is imposed by the nature of the biophysical context (scarcity of natural resources, climatic uncertainty, etc.) and the socio-economic context (risk, strategies of adaptation of production systems, etc.).

6.2 Economic diversification in the Tunisian Jeffara

The conditions of household income shed light on the importance and significance of the nature of multi-activity in the study area. It is easy to note that the main activity of the heads of household, and therefore the main income, does not derive from agriculture, particularly in

Main activity	Beni Khedache	Medenine Nord	Sidi Maklouf	Mareth	Study area (Jeffara region)
Agriculture	14.07	20.37	19.43	16.95	17.22
Workers	34,82	38,89	44	33,9	37,91
Tertiary	24.35	20.37	20.57	20.76	21.36
Pension & assistance	22.96	20.37	7.43	21.19	17.38
Without activity	3.70	0.00	8.00	3.81	4.64
Others	0.00	0.00	0.57	3.39	1.49
Total	100.00	100.00	100.00	100.00	100.00
Number	135	58	175	239	609

Table 3. Activity of the head of household providing the main source of income.

Source of the incomes	Beni Khedache	Medenine Nord	Sidi Maklouf	Mareth	Study area (Jeffara region)
Main income	59.05	70.67	65.07	71.16	67.02
Complementary incomes from secondary sources					
Agriculture	3.86	8.93	4.04	2.99	3.99
Breeding	4.00	8.34	5.34	5.56	5.36
Trade	7.97	4.05	3.92	2.41	3.57
Building sites	4.82	2.99	4.54	5.14	4.98
Craft industry	0.65	0.00	0.68	2.85	1.66
Services	0.25	0.03	2.51	0.98	1.13
Building	6.00	3.20	1.33	1.48	2.49
Public office	5.30	0.00	2.70	2.66	3.04
Migration transfers	4.68	0.00	4.62	2.10	3.16
Pension & retirements	1.32	0.63	3.95	0.98	1.80
Government aid	0.61	0.27	0.00	1.33	0.73
Others	1.50	0.88	1.28	0.35	1.07
Total of the complementary incomes	40.95	29.33	34.93	28.84	32.98
Total incomes	100.00	100.00	100.00	100.00	**100.00**

Table 4. Distribution of the average annual income of households according to the origin of the household incomes.

the mountain (*jebel*) and piedmont areas. Handicrafts, construction work, tertiary activities (trade, transport, hotels, restaurants, etc.), with administration among the main sources of household income (Tables 3 and 4).

Agricultural activities are therefore gradually declining in importance. Indeed, the proportion of heads of household with agriculture as a main source of income is only 17.2 % whereas 26.8 % are from paid salary activities (workers). The service activities represent 21.4 % of cases (Picouet, 2003).

Table 6 shows the extreme diversification of income-generating activities in the Tunisian Jeffara.

Number of incomes	Beni Khedache	Northern Medenine	Sidi Maklouf	Mareth	Study area (Jeffara region)
Only one income	24.82	25.86	40.00	38.08	34.65
Several incomes	75.18	74.14	60.00	61.92	65.35
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 5. Proportional distribution of the number of sources of income of the household

Number of incomes	Beni Khedache	Northern Medenine	Sidi Maklouf	Mareth	Study area (Jeffara region)
An activity and an income	25.55	27.59	41.14	39.75	35.80
An activity and several incomes	11.68	3.45	2.86	17.15	10.51
Sub-total only one activity	37.23	31.03	44.00	56.90	46.31
Two activities	39.42	24.14	38.29	31.38	34.48
Three activities	22.63	43.10	17.71	11.72	18.88
Four activities and more	0.73	1.72	0.00	0.00	0.33
Sub-total multi-activity	62.77	68.97	56.00	43.10	53.69
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Average activity number/ household	1.87	2.16	1.74	1.55	1.73

Table 6. Distribution of the households according to the number of activities of the household heads.

The following observations can be formulated:

- the low proportion of incomes generated from agriculture representing an ancillary activity (4 % of income);
- the relative importance of the contribution from breeding activity (5.4 % of income);
- the apparent weak contribution of handicraft activities (1.6 % of income). This translates as difficulties in the valorization of the abundant and rich resources in the area;
- the weak contribution of services activities (1.1 % of income). There is an opportunity to improve the situation;
- the relative weakness of incomes derived from emigration (3.2 %). It seems that incomes from emigration are considered as an auxiliary source and not as a main source. Nevertheless, the contribution of emigration could be very high for certain individual households. For example, the average income of emigrating households in the mountainous zone of Beni Khédache, considering the importance of emigration, is estimated at 4,725 DT/year (approx. USD 3,800).

The diversity in terms of the main sources of income is remarkable. Only few households are satisfied with only one source of income. The diversification of incomes is confirmed by the importance of households that have recourse to several sources of income (65.4 %) whereas 34.6 % have only one source of income (Table 6). This phenomenon is particularly important in the Jebel and piedmont zones and in the northern zone of Médenine where it reaches 75 % of households i.e. 15 % more than in the other two counties located mainly in the coastal plain (Table 5).

This strategy is coupled with another strategy based this time on social solidarity between the members of the

County	Main income			Complementary income			Total		
	N	Avg.	Std Var	N	Avg.	Std Var	N	Avg.	Std Var
Beni Khedache	131	1821.15	1726.09	101	1579.73	2180.4	137	2906.01	2637.26
Northern Medenine	58	1943.1	1315.79	43	1107	1014.74	58	2763.81	1766.17
Sidi Makhlouf	161	1898.24	1656.66	104	1577.8	1929.07	175	2684.04	2425.38
Mareth	221	2492.79	2615.41	139	1534.74	1777.82	229	3337.05	3271.28
Study area (Jeffara region)	571	2115.22	2086.78	387	1510.53	1867.48	599	2992.18	2784.04

Table 7. Estimation of the income of the household heads in the Jeffara.
Source: Principal Survey Jeffara (April 2002)

	Main income			Complementary income			Total		
	N	Avg.	Std Var	N	Avg.	Std Var	N	Avg.	Std Var
Jebel	49	2121.43	1792.93	35	2541.97	3353.48	50	3857.38	3327.4
Piemont	129	1993.86	2122.52	96	1455.86	1554.65	134	2962.47	2546.73
Central plain	116	2079.64	2244.57	78	1456.92	1664.46	123	2885.19	3157.68
Costal plain	277	2185.55	2057.51	178	1360.69	1645.28	292	2902.73	2603.31
Study area (Jeffara region)	571	2115.22	2086.78	387	1510.53	1867.48	599	2992.18	2784.04

Table 8. Income of the household head as a function of the geophysical zones in the Jeffara.
Source: Sghaier et al.. 2003

household. Indeed, 30 % of the households have incomes generated by other family members. The income of households in the Tunisian Jeffara is primarily derived from a non-agricultural income (82 %), whereas agriculture and breeding represents only 10.6 % and 6.6%, respectively. Average income of households is estimated at 2,992 DT/year * (~ USD 2,400) with a standard deviation of 2,784 DT/year (~ USD 2,200), and a minimum of 300 DT/year (~ USD 245) and a maximum of 22,000 DT/year (~ USD 18,000). Apparent disparities between the various counties have been noted. In fact, the average annual family incomes are 3,337 DT in Mareth (~ USD 2,700); 2,906 DT in Beni Khedache (~ USD 2,300); 2,764 DT in Northern Médenine (~USD 2,200); and 2684 DT (~USD 2,100) in Sidi Makhlouf (Table 7).

* current conversion: 1 TND=0.824 USD

The spatial analysis of the total income of households show disparities between the zones whose average income exceeds 4,000 DT/year such as Southern Mareth (8,200 DT/year), Sidi Touati (4063 DT/year), Rahala (4,033 DT/year) and others, where the income does not exceed 2,000 DT/year like Toujene (1,146 DT/year). As shown in Table 8, complementary incomes alone make up the difference between the various zones. For example, this income is about 2542 DT/year in the zone of Jebel whereas it is about 1,361 DT, 1,456 DT and 1,457 DT in the costal plain, piedmont and the central plain zones, respectively.

Analysis of income classes per county and by geophysical zone reveals that the majority of farmers belong to the middle-class where incomes do not exceed 1,500 DT; 26% of households declare that their incomes range between 500 and 1,000 DT with 21% between 1,000–1,500 DT. The county of Médenine North shows an important proportion of households with incomes exceeding 2,000 DT and sometimes as much as 6,000 DT. By geophysical zone, the Jebel is characterized by a high presence of farmers who gain more than 2,000 DT/year. The analysis reveals a high diversity in terms of annual expenditures of heads of household. Indeed, in the Jeffara zone, farmers spend on average 3,189 DT/year, the most significant part is attributed to domestic expenditures averaging 1,344 DT/year. As regards agricultural expenditures, the average is estimated at 450 DT/year. In the areas of Mareth and northern Médenine, farmers invest more in agricultural activities (approximately 600 DT/year) than in the areas of Beni Khedache and Sidi Makhlouf (approximately 300 DT/year). Conversely, for water related expenditures, the total average in the zone is approximately 225 DT/year (~USD 208). At the level of geophysical zonation, 48 % of households in the coastal plain declare spending around 3,322 DT/year on general expenses, 22% in the piedmont zone and 21% of households in the central plain spend less than 3,000 DT/year. Finally, 9% of farmers of the jebel declare spending around 3,251 DT/year. The elevated trend towards water expenditure and the agricultural sector is recorded in the central plain with an average of 265 DT/year and 588 DT/year, respectively. The spatial analysis of the total expenditure of the households reveals that households that exceed the mean level recorded in the catchment area are located in southern Mareth (5,967 DT/year) and El Alaya (4,165 DT/year) whereas households with low expenditures are situated in Toujène (1,335 DT/year), Beni Khedache (1,822 DT/year) and Gosba (1,921 DT/year).

6.3 Examples of income-generating activities

6.3.1 Ecotourism

Five out of the six NGOs involved in the project have chosen ecotourism in the drylands as one of the main axis of their intervention programs.

In the regions of Médenine the following NGOs: AJZ (*Association des Jeunes de Zammour*), APBB (*Association de Protection de la Biodiversité*) and ADD (*Association de Développement Durable*) has initiated an ambitious ecotourism program in the mountain area of Beni Khedache which is distinguished by:

- *Natural patrimony*: the diversity of the natural landscapes (mountains, hills, biodiversity, etc) combined with thousand-year old local know-how in water resources management are extremely visible in the landscapes: jessour, Roman remnants, palm plantation and so on.
- *Architectural heritage*: the presence of several ksars and troglodyte dwellings presenting a very strong image of human occupation.
- *Local know-how*: arts and crafts in addition to agricultural product transformation and storage.

ADD is now experimenting with excursion tourism in the valley of Zammour where tourists are lodged in guest houses in order to experience first-hand the daily lives of local families. On the other hand, APB, supported by all the project partners, is lobbying for the creation of a national park around the Nagab mountains. The request in underway and there's a likelihood that this will happen; it will represent a vital centre for biodiversity conservation but also for ecotourism related activities (Figure 9). In the region of Tataouine (where Star Wars was filmed), AAMTT has already set up its Jurassic park geological circuit and the geological museum. Meanwhile, ASNAPED is operating a typical Berber mountain hostel in the village of Douiret.

6.3.2 Erg sand based handicraft

Following the study on the potential of income-generation activities conducted in 2005, as well as recommendations of the national workshop of 2005, the SUMAMAD project assisted two local NGO partners in implementing common income-generation activities.

Figure 2. Margine spreading for soil stabilization and sand movement control.

The idea was first developed by the AMTT of Tataouine. It consists of developing erg sand produced handicrafts using simple techniques. A member of AAMTT, Mr Marino Zecchini, volunteered to provide training to ten teachers at the Centre for the Mentally Handicapped of Médenine where he organized three sessions introducing the technique and making practical applications. The teachers then successfully took over to teach and train their students using the same technique. The teachers quickly understood the technique and it was noticed later that they even started innovating. Together with their students, they produced a variety of erg sand based handicrafts which were sold to visitors of the centre (Figure 10). A 10 min film summarizing the main steps of this process was produced and can be viewed on the SUMAMAD website: http://www.unesco.org/mab/ecosyst/drylands/Sumamad.shtml

7. Results obtained

7.1 Physical environment

7.1.1 Exploitation of the olive waste water 'margine'

Because of the harmful effects of margine on the environment (pollution, biotope destruction, etc), and the consequent corrosion and blockage of sewage pipes, the disposal of margine in the public wastewater discharge network or in nature (water courses, etc.) is strictly prohibited; owners of olive mills are obliged to store it in individual or grouped ponds (Arambari & Cabrera, 1986; Berndt *et al*., 1996; S'habou, 2002). However, this solution is only provisional considering the increase in the quantities of margine and the risks of infiltration. The alternative solutions include, direct spreading on the olive groves or use as a stabilizing material in grazing lands to control wind erosion. This work is in fact part of an already on going program conducted by IRA and IO (Institut de l'Olivier); the trials consist of spreading margine in the inter-row area between the olive tree rows. In addition to the control plot, three plots with different application doses are considered: 50, 100 and 200 m^3 per ha. The same cropping operations are maintained on all the plots. Each plot covers an area of 1 ha in the OTD (*Office des Terres Domaniales*) farm of Chammakh (Zarzis). The following various impacts are being monitored:

- Chemical properties of the soil: pH, electrical conductivity, organic matter, cation exchange capacity, N, P, K.
- Soil physical properties: infiltration, aggregation, water retention, available water.

Although margine is acidic (pH 5.5) successive applications of different doses of margine did not affect soil pH. Only a slight rise in pH was observed, from 7.4 to 7.9 with T3, which could be attributed to a high concentration of calcium in the sandy soil. This phenomenon has also been reported by Levi-Menzi *et al.* (1992), Della Monica *et al*. (1978) and Potenz *et al*. (1985) who attributed this slight increase to the production of ammonia during the breakdown of organic matter.

In spite of the high salt content of margine, the permeability of the sandy soil allows the slats to leach and hence prevents an increase in electrical conductivity (EC) of the soil. Values of EC recorded after eight years still show low EC values with a maximum of 3.85 mS/cm for the highest dose T3. However, one should also take into account the change in EC as a function of time, as EC strongly depends on weather (rain) conditions. After a dry period, the EC can rise to 10 mS/cm to later fall to 3.85 mS/cm because of rainfall and salt leaching.

Rich in organic substances (107 kg/m^3), the margine also increases the soil organic carbon content. However, three months after each application, a small decrease in the organic matter content was observed possibly due to the mineralization of the organic substances by micro-organisms under optimal humidity and temperature conditions. The organic carbon content, initially very low (0.03 to 0.1%), increased after six applications, during the eight-year period, to values of 0.29% for the dose of 50 m^3/ha of margine, to 0.40% for the dose of 100 m^3/ha of margine and to 0.77% for the dose of 200 m^3/ha of margine. This enrichment in organic compounds reflects the amelioration of the chemical and physical fertility status of the soil, which consequently can improve the growth of the olive trees and the production of olives. Cabrera *et al*. (1996) found similar results with yearly applications of margine on a sandy soil, initially containing 0.45% of organic matter. Applying 37 or 61 l/m^2 of margine during three successive years increased the organic matter content to 1.62% and 1.98%, respectively.

Although margine contains high amounts of potassium (7.5 kg K/m^3 corresponding to 1,500 kg K/ha/year with the dose of 200 m^3), the potassium content in the soil was not subject to pollution risk. Following the six applications, the assimilated K content increased from 115 ppm in the control to more than 190 ppm in the plot, which received 50 m^3/ha, to more than 500 ppm for the dose of 100 m^3/ha, and to more than 950 ppm for the 200 m^3/ha dose. Cabrera *et al*. (1996) indicated that for an initial content of 1.3 mmol/kg of exchangeable potassium in the soil, applications of margine at doses of 37.3 or 61 l/m^2 increased the exchangeable potassium concentration to 53.3 and 60 mmol/kg, respectively. Because of leaching, the K concentrations found in our study are low and will not negatively affect the soil quality.

Margine contains on average 1.4 kg of total nitrogen and 0.32 kg of phosphate per sq. metre. After the six application of margine at quantities of 50 to 200 m^3/ha, the N and P content did not increase. Starting from an initial value of 0.035% of total nitrogen in the four plots, no changes in nitrogen were observed with T1, a slight increase to 0.044% N with T2 and to 0.059% N with T3, although the latter application (200 m^3) corresponded to 148 kg N/ha/year. Those low N contents in the soil after all the applications can be attributed to leaching in the sandy soil, and also because of the high demand for nitrogen for olive tree growth and production. The same conclusion is drawn with regard to phosphorus. The contents varied between 15 and 17 ppm in the four plots and did not change after the six applications.

Soil aggregation can be considered as an indicator for soil structure. Increasing the aggregate size, and hence the roughness of the soil surface, can decrease the erodibility from wind erosion (deflation). Soil samples were taken from the upper 5 cm layer. The aggregate size distribution was determined by dry sieving and the following aggregate size fractions were considered: 0 – 0.5 mm; 0.5 – 1.0 mm; 1.0 – 2.0 mm, and 2.0 – 10.0 mm. The three smallest fractions refer to micro-aggregates and the largest fraction refers to macro-aggregates (> 2.0 mm). Figure 3 illustrates the aggregate size distribution for the four sampling dates and different margine doses. Compared to the initial situation, a remarkable decrease in the smallest aggregate size fraction (0.0–0.5 mm) could be observed, resulting in an increase of the macro-aggregates especially in the fraction 0.5–1.0 mm but also in the percentage of macro-aggregates (2.0–10.0 mm). The larger the aggregates, the lower the capillarity, and because of the hydrophobic character of the margine the large aggregates act as a mulch preventing upward movement of water (evaporation). This aggregation has also been observed by Mellouli (1996), Ben Rouina & Taâmallah (2000), and Abichou (2003). Gabriels *et al.* (1975) already demonstrated that when a sandy soil was treated with a hydrophobic bituminous emulsion, the aggregates formed had better stability, and when placed at the soil surface, substantially reduced evaporation.

The soil water retention curve and the saturated hydraulic conductivity were determined on the 0.0–30.0 cm layer soil samples. A decrease in saturated hydraulic conductivity with all treatments was noticed. This can be attributed to the hydrophobic characteristic of margine, which decreases the water transmission rates through the upper soil layer especially within the small aggregate fractions. But once the water has entered (infiltrated) across this layer it is made more available to plants, shown by the increase in moisture content at wilting point and field capacity, and also with more than 4 mm in water holding capacity for the highest dose T3.

7.1.2 Water harvesting and flooding risks

One of the roles assigned to the soil and water conservation works is the attenuation of flooding risks in the urban areas. This work aims at describing the exceptional floods of 1969, 1973 and 1979 with a focus on the evaluation of the effects of the flood of 26 September 2003 as well as the behavior of the soil and water conservation structures at the level of the wadi Hajar (province of Médenine) watershed (Figure 4). Use was made of:

- Historical rainfall and flood records (1969–2003),
- Conducting field surveys (GPS) and GIS,
- Carrying out 37 questionnaires and interviews of farmers and riverside inhabitants.

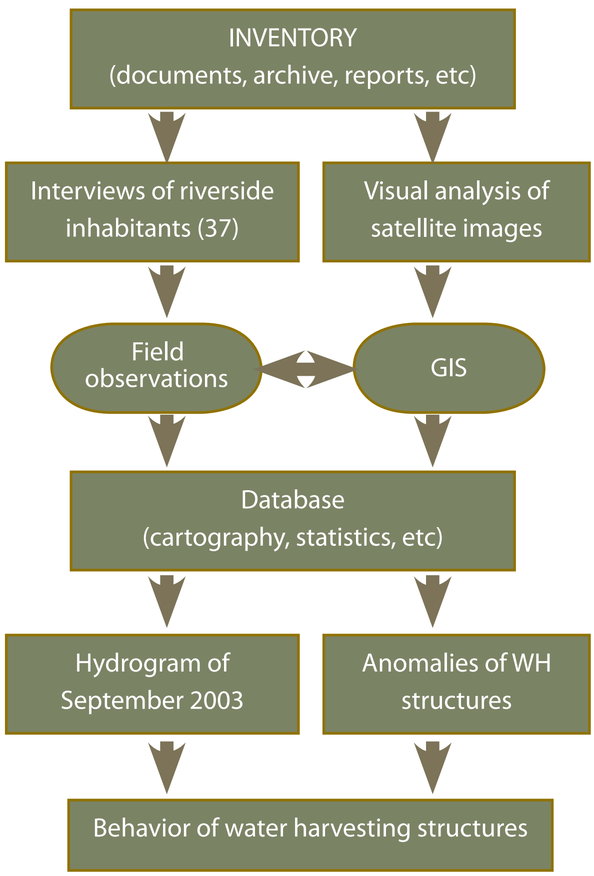


Figure 3. Methodological framework.

	1969	1973	1979	2003
Rainfall days	03 days (5 - 7 october)	07 days (du 19 et 20, 4 et 5 December, 12 et 13 December)	11 days (24/02 to 02/03 and 3/3 to 6/3)	26 September (03 hours)
Rainfall (mm)	Médenine 147,1	Médenine 58,3	Médenine 171,2	Méd / Ouerj 32,1 / 69,9
Max Intensity (mm/h)	–	–	70 mm/h in 5 minutes	**120 mm/h in 30 minutes**
Max outflow (m^3/s)	(Oued Gabès) **65**	(Oued Gabès) 04/12/73: 57 12/12/73: 142	Oued Hajar 150	Oued Hajar **353,28**
Water height (m)	Start / Max / End 0,7 / **2,5** / 0,5	–	Start / Max / End 0,7 / **1,8** / 0,5	Start / Ma x / End / Start 1,25 / **3,15** / 0,9
Damages	Limited damages of SWC structures + Destruction of the bridge in Médenine	Damages of small hydraulic units and the main road in the viscinities of Kasr Jedid	Huge important damages	Medium damages of SWC structures, gabion check dams, and the infrastructures.
Flooded areas (ha)	**128** **30 ha in downstream** **98 ha in upstream**	-	-	**1692** **15 ha downstream** **1677 ha in upstream**

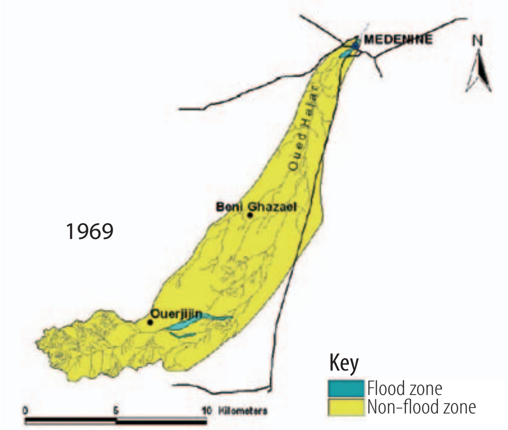
Table 9. Summary results.

It was found that despite the damages, anomalies and failures recorded during the event of September 26 2003, the soil and water conservation structures (jessour, tabias, gabion recharge and spreading check dams, etc.) played an important role in alleviating the flooding risks, especially for the town of Médenine.

In addition, this study contributed to the establishment of an important database comprising statistics and digital maps, which can be regularly updated and used as a support for decision-making when required, and as regards future plans of watershed management and flooding mitigation in the province of Médenine.

7.1.3 Evaluation of soil and water conservation structures

A tool to evaluate water harvesting structures was developed by the adaptation of the procedure conducted by Bracmort (2004) for the evaluation of best management practices in the Black Creek watershed in Indiana, USA and Brafalgha (2006) for an application in Tunisia. The tool requires the evaluator(s) to rate structural characteristics by physical inspection and to compute an overall score on condition.



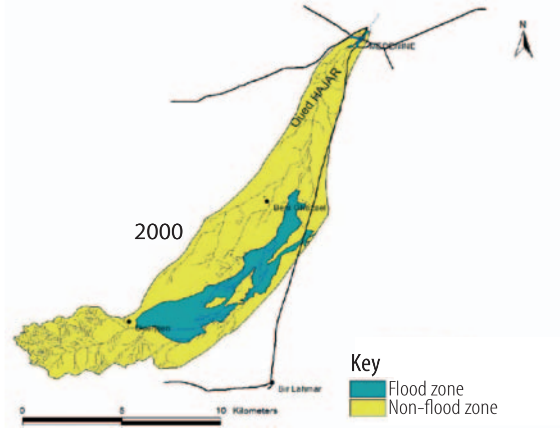


Figure 4. Example of mapped results, flooding of 1969 and 2003

The evaluation tool includes an introduction of the evaluation, as well as:

1. a description of the structures to be evaluated;
2. a list of materials needed;
3. instructions on the use of the tools that include:
   a. Quantitative code description for the different structural characteristics;
   b. Computation of the overall structure condition score based on the quantitative code data above;
4. Guide for the selection of the quantitative code described above; and
5. An actual evaluation data sheet and criteria used for evaluating the final condition score.

At the same time, a specific socio-economic evaluation questionnaire was also prepared. It mainly covers: control of the rural exodus, improvement of living conditions, and overall development of the region.

A sample of practices along the wadi Koutine within the wadi Oum Zessar watershed was evaluated using the evaluation tool. A total of 55 interviews were conducted and 142 structures were evaluated (Table 10).

The technical evaluation revealed that the general state of the undertaken works is considered good to satisfactory. The catchment area is treated with the various

Surveys	Compartment			
	Upstream	Piedmont	Downstream	Total
Socio-economics	18	23	14	55
Technical				
Contour stone ridges	16	3	6	25
Tabias	32	32	37	101
Jessour	19	8	11	38
Recharge	67	17	14	98
Spreading	8	8	0	16
Total	**142**	**68**	**68**	**278**

Table 10. Interviews and evaluated structures.

structures while respecting the technical requirements of the sites. In this respect, one can notice the general trend towards the intensification of actions for water retention (tabias, jessour, gabion, etc) at the expense of small dry stone ridges, which are meant essentially for gully corrections. The evaluation also showed that the installed structures are well exploited by the fruit tree orchards, annual crops, etc., as well as by rangelands improvement.

On the socio-economic level, the implementation of the strategy did not sufficiently stop the rural exodus. Conversely, it improved the labour market, confirmed by 91.3 % of the interviewed population. Moreover, 63.3 % of the farmers participate in the selection of techniques.

The implementation of actions of the strategy helps promote the other sectors of the economy such as trade, small businesses, and services. However, their expansion depends on the presence of farmers, and it was also noted that the level of their income is closely related to rainfall regime. Implementation of the strategy preserved the natural resources, enabled the launch of a process of agricultural development, and improves the incomes of the local population.

To ensure a more sustainable and coherent development of the zone, it is necessary to promote other economic sectors like ecotourism, handicrafts, medicinal and aromatic plants, etc. It also means that the objectives and purpose of the soil and water conservation structures should evolve in the same way. The adoption of the three implementation methods: public sector, entrepreneurial, and private (farmers) sector was found to be successful as it ensures that all the partners contribute towards combating soil erosion, and the preservation of natural resources.

7.1.4 Rangeland rehabilitation techniques and their impacts on natural vegetation dynamics

Since the 1950s, cropping was extended and traditional grazing systems (transhumance and nomadism), which had historically allowed for grazing deferment and control of grazing livestock, were abandoned. Almost all rangelands in pre-Saharan Tunisia (mean annual rainfall 100–200 mm) are now grazed continuously without any restriction on stocking rate. Such changes have led to the deterioration in the condition of the rangeland. The ensuing soil degradation and the loss of palatable perennial species are two of the direct results of the recent anthropogenic pressure on arid rangelands in Tunisia.

Several attempts have been made to restore and rehabilitate degraded rangelands in Tunisia's arid zone with exotic herbaceous species and shrubs. All these efforts however have largely failed due to the inability of the introduced species to adapt to the ecological constraints of the region. The objective is to determine the effects of restoration/rehabilitation operations undertaken by development agencies on the natural vegetation of the study area in the Jeffara region.

The experiment was conducted on different sites of the study area in the sandy steppes (dominated by *Rhanterium suaveolens* when the steppe is in good condition) (Table 11). It involved four different treatments: overgrazed areas, fallows, protected areas (restoration) and rehabilitated areas (planted with shrubs). The condition of the soil surface, plant cover, species composition, flora diversity, as well as range value and grazing capacity of the studied sites are determined by the point-quadrats method. Measurements were made during the spring.

The main results are presented in Figures 5 and 6.

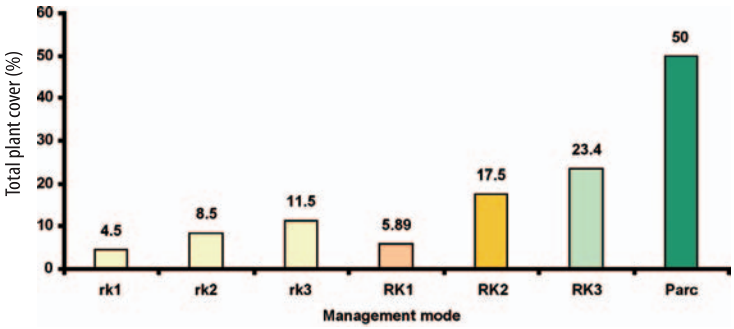


Figure 5. Variation of vegetation cover in relation to the management mode.

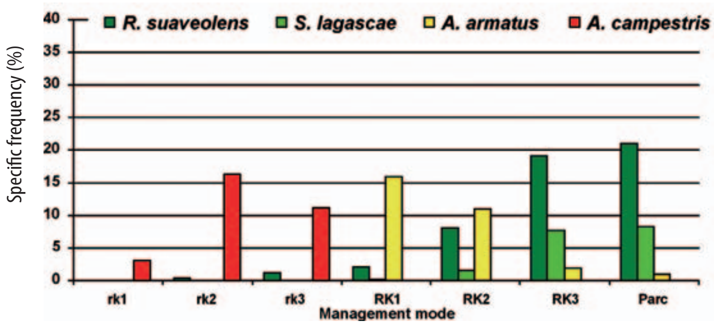


Figure 6. Variation of species frequency in relation to the management mode.

Mode	Code
Post-cropping parcels (0-5 years)	rk1
Post-cropping parcels (5-10 years)	rk2
Post-cropping parcels (10-20 years)	rk3
Degraded rangelands by overgrazing	RK1
Fairly degraded rangelands by overgrazing	RK2
Long-term closed rangelands	RK3
National park of Sidi Toui	Parc

Table 11. Different rangeland management methods.

Preliminary results show:

- the invasion of the abandoned fallow parcels by *A. campestris*, a low range value species, depending on the period of abandon;
- the invasion of the overgrazed rangelands by spinus and upalatable species such as *A. armatus*;
- in the absence of disturbance, *R. suaveolens*, the key species of the steppe, dominates the vegetation cover;
- *Stipa lagascae*, a perennial grass of high range value, has completely disappeared because of cropping; its presence in RK1 is evidence of its resistance to overgrazing.

7.5 Socio-economy

7.5.1 Application of multi-objective and compromise programming for optimal allocation of natural resources

A multi-objective programming model was conceived using the Non Inferior Set Estimation (NISE) method (Romero *et al*., 1989). This modeling test helped develop an optimal allocation of groundwater resources within the production systems in the Oum Zessar watershed. The model reconciles the two conflicting objectives:

- Maximization of gross margin (economic objective).
- Minimization of the cost of soil degradation (environmental objective).

The method of contingent evaluation and the method of multi-objective programming were used. The mathematical formulation of the model is described below:

Max GM = $\sum$ (GM)ijXi j

Min $\sum CD_{ij} X_{ij}$

Knowing all the constraints: $\sum_{i=1}^{n} aijxj \leq bi$

C_{Dij}: The cost of soil degradation of the production system J found in the layer (part) J.

GM : Gross margin at the scale of the watershed.

GM_{ij}: Gross margin per hectare of the production system in the layer J.

	Objective functions (TD)		Soil occupation (ha)					
	Max GM	Min SD	X_{11}	X_{21}	X_{22}	X_{31}	X_{32}	Total
Optimal solution	3073187	566122	5397	9080	3120	4664	41	22302
Reference situation	1580447	380099	3120	728	3120	4664	41	11673

Table 12. Optimal solution of simultaneous optimization.

GM: Gross Margin, DS: soil degradation, X_{11}: jessour system of upstream, X_{21}: jessour system of piedmont, X_{22}: embankment system of piedmont, X_{31}: system rainfed agriculture in the plain, X_{32}: system irrigated perimeters in the plain.

X_{IJ}: occupied area (ha) by the system of production I of the layer J.

N: number of production system at the level of the watershed.

The application is based mainly on a survey concerning 240 farmers in the watershed of Oued Oum Zessar. The survey was made of two main parts: the first part was related to the inherent contingent evaluation methods in order to estimate the land degradation costs. It estimates the willingness of each farmer to pay in order to protect 1 ha of arable lands. The second concerned the socio-economic characteristics of the farmers (age, education level, family situation, agricultural activities and production, expenditures, income, etc.).

Table 12 and Figure 7 summarize the results of simultaneous optimization of the model in comparison with the initial reference situation. The results show that the jessour systems in the upstream and piedmont areas are in a better position to compete in a compromise situation, and also still have potentialities to maximize the economic results without enduring high degradation costs.

7.5.2 Economic efficiency assessment

A logarithmic Cobb-Douglas production function (Mahdhi *et al.*, 2005) was chosen to evaluate the economic efficiency of SWC techniques in the watershed of Oum

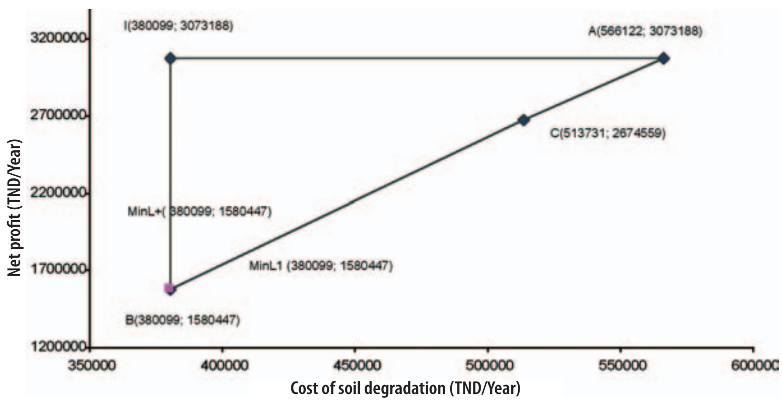


Figure 7. Tradeoff function of soil degradation.

Zessar. It takes the form:

$$\text{Log } Y = \text{Log } A + \beta_1 \log x_1 + \beta_1 \log x_2 + \beta_1 \log x_3 + u$$

Where the endogenous variable Y is the average fruit tree production per hectare; and the exogenous variables retained are: x_1, the number of hours of animal and mechanical haulage used for the work of the land per year; x_2, the number of working days paid and of families engaged in the production process (maintenance of the work) per year; and x_3 the annual rainfall. The Corrected Ordinary Least Squares (OLS) method was used.

When considering the frontier production, the results showed that the farm (rainfed agriculture) produced on average 55, 70 and 70% of the output frontier in the upstream, piedmont, and downstream compartment,

	Upstream	Piedmont	Downstream	Watershed
Mean Average	0.55	0.70	0.70	0.65
Maximum	0.75	0.93	0.94	0.86
Minimum	0.43	0.56	0.48	0.52
Standard deviation	0.096	0.090	0.155	0.095

Table 13. Average economic efficiency (% of the frontier production) by watershed compartment (1986–2000).

respectively (Table 13). Therefore, it seems that it is possible to increase the production of rainfed agriculture to reach the frontier production when better use is made of the production factors, which would reduce production costs and consequently improve its competitiveness.

7.5.3 Elaboration of the local action plan for combating desertification and development in the region of Beni Khedache

Within the framework of the implementation of the UNCCD and the National Action Plan for Combating Desertification (NAP-CD), and as a request formulated by the local actors, the SUMAMAD team partly assisted in the elaboration of the local action plan for combating desertification and development in the region of Beni Khedache. It was lead by the Ministry of Environment and Sustainable Development and supported by GTZ.

It was based on a participatory approach and conducted in two main phases:

- *Phase 1*: Bio-physical and socio-economic synthesis: It was conducted by the inventory of all the available documentation but, in addition, a series of meetings and surveys were performed with the assistance of the local population as well as other local partners involved in the process (agriculture, environment, infrastructures, tourism, culture and so on).
- *Phase 2*: Elaboration of the local action plan for combating desertification and development: the plan prepared by the working team (agriculture, environment, SUMAMAD team, GTZ) was debated in open meetings with the local population and the key partners. Following numerous discussions and debates, the final plan was approved and was sent to the ministry to seek funding from the national budget and/or other funding agencies.

The plan comprised the following:

- Biophysical characteristics.
- Socio-economic characteristics.
- Infrastructures.
- Main development problematic.
- Action plan for combating desertification and local development: agriculture, soil and water conservation, sand fixation, rangelands and livestock, non agriculture income-generation activities, infrastructures, and institutions.

8. Recommendations and conclusions for sustainable dryland management

8.1 Soil and water resources

The spreading of margine showed the potential use of this olive wastewater for not only improving the chemical fertility status of sandy soils but also for improving the soil's physical characteristics such as moisture content at wilting point and field capacity, especially with the highest rates of margine applications (200 m^3/ha/year). Spreading of 1 m^3 of margine on the soil adds 107 kg of organic matter, 1.4 kg of nitrogen, 0.34 kg of phosphate and 7.5 kg of potassium. So far, the application of margine did not cause any salinity problems even at the highest application rate of 200 m^3/ha per year although an increase in aggregate size was observed, which could reduce the risk of deflation by wind. The saturated hydraulic conductivity decreased due to the action of the hydrophobic character of margine especially in small aggregate fractions. On the other hand, these larger aggregates and the hydrophobicity can help reduce capillarity and subsequently the upward movement of water (evaporation). With regard to the water status in sandy soils, a remarkable increase in moisture content at field capacity and at wilting point was observed especially with the highest dose of margine application. As margine improved the water status of the sandy soil, its effect on olive tree growth and the production of olives should be subject for further investigation. Those results are being discussed with development agencies, mainly the CRDA (Regional Department of the Ministry of Agriculture and the farmers union), so as to proceed for application on a larger scale following a step by step strategy. At the same time, other research investigations are continuing with IO to study the effects of margine on deflating sand stabilization as well as rangeland improvement.

Water harvesting techniques or soil and water conservation systems have mainly been assigned the role of supporting rainfed cropping and providing drinking water for domestic uses and animal consumption. They continued to function in that manner until the beginning of the second half of the twentieth century when new social and economic upheavals and technological developments started to raise problems of viability and economic efficiency and thus any possible extension and expansion of these practices should be seriously questioned. However, water harvesting techniques may perform additional indirect functions such as flood prevention, groundwater recharge, and erosion control, which do normally not accrue to the investor alone. In fact, huge investments have been made to maintain the old water harvesting systems in the region and to establish new ones whose effects and efficiency needs are ascertained through evaluation and assessment. The developed methodology of water harvesting evaluation assessment applied for the study area clearly showed the vital diverse roles of those systems: soil water increase, soil conservation, flooding control, ecosystem improvement, direct and indirect income improvement, and so on. However, to ensure a more sustainable and coherent development of the zone, it is necessary to promote other economic sectors such as ecotourism, handicrafts, and the medicinal and aromatic plant industry. It also means that the objectives of the soil and water conservation structures should evolve in the same way. The developed assessment methodology can be subject to further improvements but can also be later integrated to other tools/models to produce a more holistic tool to be used by practitioners, extension agents, farmers and so on.

8.2 Rangelands

In southern Tunisia, the natural vegetation cover is mainly dominated by steppic plant communities. It is schematically about grassland on the high southern plains and chamaephytic formations in the low southern plains and Jeffara. For several decades, the natural vegetation cover is continuously degraded by various human activities especially as we know that grazing is practiced continuously without any restriction on stoking rate. Besides, the ever extension of cropping lands (mainly for olive plantations or annual cereal cropping) aggravate further the situation and lead to increased overgrazing.

Among the most effectively used techniques for the preservation of this floristic heritage we find protected area restoration which regenerates the natural vegetation cover even in the most disturbed sites. However, the livestock herders cannot benefit directly from those protected areas so it is recommended to test other management techniques such as:

- Resting of collective or private rangelands.
- Reseeding of degraded rangelands with native species.

8.3 Agro-economy

Approaching desertification only from a technical angle is now completely insufficient in terms of the viability of long-term actions to combat desertification. The complexity of relations between rural societies and their environments must be taken into account, and on a global scale, as the implication of communities has proven to be crucial in the design and implementation of CD policies. The significance of the integration of combating desertification and sustainable development concepts is expressed in multi-sector stakes insofar as resource uses appear among communities within the context of full social and economic change.

If agriculture today is no longer the dominant activity as regards rural household incomes, other prospects should be considered in terms of 'strategies of rural innovation', which consider regional characteristics and assets as well as valorization of the local resources, thereby privileging multi-functionality in terms of agriculture in particular, and rural areas in general.

Figure 8. Overgrazing of rangelands leads to degradation.

As regards the multiplicity of actors and the very active role of the State, methods of intervention should better adapt to the new conditions of rural development policies that promote a closer integration of sectoral operations and notably a true implication of the rural population in the formulation and control of actions to which they are associated. Thus, development strategies and actions to combat desertification should in the future be based on a global, integrated, multi-sector and multipurpose solution that mobilizes all possible energies and resources. Accordingly, combating desertification becomes an integral part of the dynamics of sustainable local development.

8.4 Income-generation

Experience in our collaboration with NGOs showed that they have great willingness and enthusiasm to actively contribute towards the improvement of the local, natural as well socio-economic environments in which they operate. Because of the harsh climatic conditions such that the traditional agricultural sector cannot generate sufficient resources for the local population, NGOs are working hard to promote alternative and diversified income-generating activities. Small but solid steps have been achieved but further actions are recommended such as:

- realization of a field survey to identify concrete income-generating activities and to evaluate their feasibility;
- organization of training courses for the development of income-generating activities;
- organization of internal and/or foreign visits to exchange results on the field experiments on projects based based on income-generating activities;
- promotion of actions in the fields of:
  – valorization of local agricultural produce, the natural heritage, and socio-cultural wealth.
  – promotion of ecological and cultural tourism.
  – development of handicrafts and small businesses.

Figure 9. Troglodyte dwellings and mountain landscape: a huge potential for ecotourism in the region.

Figure 10. Sand based handicrafts prepared by the centre for the handicapped of Médenine: an interesting source of income-generation.

8.5 Comments and discussion

The main beneficiaries of the project activities can be grouped into three main categories:

Research: It includes the IRA's team and colleagues from L'Institut d'Olivier. This group is backed by the University of Ghent, Belgium. (Prof. Gabriels).

Development: It concerns the regional department of the Ministry of Agriculture (CRDA). Three main sections are involved: Soil and water conservation (Médenine), water resources (Médenine), extension (Béni Khédache).

Local communities: Six NGOs have been involved but with a main focus on income-generation activities and local development.

Progress towards the SUMAMAD project objectives:

- Based on the SUMAMAD assessment methodology (Adeel and King, 2004), it was very hard to apply this methodology to progress during the annual activities. We do recommend carrying out this exercise for the final report.

Evaluation of the sustainability of the activities during the timeframe of the project and beyond:

- The project is building on on-going activities of other programs supported by national and other international agencies.
- Most of the activities are embedded in the short and long-term strategies of the partners involved.

8.6 Conclusions

The project succeeded in:

- getting two NGOs to work together for the benefit of a group with specific needs – the disabled;
- involving the team in the active planning of a strategic local program to combat desertification.

Overall lessons learned regarding the use of participatory research methods in drylands:

- mobilization and involvement of local actors (NGOs…);
- the effective contribution of SUMAMAD in local development and natural resources management and actions to combat desertification;
- learning of partners the participative approach.

Transferable lessons on improved management approaches and livelihoods from the site:

- local action plans for CD and development,
- capacity development among NGOs,
- some research results (watershed management, land cover regeneration, soil amendment).

8.7 SUMAMAD self evaluation and recommendations

Self-evaluation	Recommendations
It is rather difficult to tackle integrated aspects with limited resources	Scale down the scope of interventions
Not a very clear focus on specific objectives resulting in patchy actions	More focus on specific objectives and actions
Heavy management procedures	Reduce the number of meetings to free some resources for actions
No application of common methodology for all sites	Better harmonization of the actions in the intervention sites
Relatively excessive reliance on other projects/programs	Reduce the degree of reliance on other projects
Very low synergies with other sites	Provide more resources for exchanges between the teams/sites

Table 14. A summary of self-evaluation and recommendations.

9. National seminars

In addition to the various informal meetings and exchanges, a national seminar was organized once a year to which all the national partners and local authorities were invited to attend. The agenda focused mainly on: the state of progress and difficulties encountered, and the program of the subsequent year (Table 15).

The program was totally practical and mainly covered:

- Routine and advanced applications of GIS ArcView.
- Basic image satellite image processing.
- Preliminary applications on the Agriculture Map (Carte Agricole) package.

Date	Participants	Outcomes
3/10/2003	21	- Early experience of the project: background, objectives main expected results.
7/12/2004	20	- State of the existing natural resources. - Traditional and contemporary techniques for natural resources and rangelands management.
23/1/2006	24	- Potential income-generating activities
22/9/2006	22	- Trial of income-generating activity based on sand. - Evaluation tools of WH.

Table 15. A summary of the organized national seminars.

9.1 Capacity building

- The SUMAMAD team assisted in training twelve NGOs members (including our partners) on the elaboration and implementation of combating desertification projects at IRA's headquarters on 26 June–1 July 2006.
- Training on GIS and RS was organized at IRA's HQ during 11–14 September 2006. It was attended by five technicians and engineers from our main partner, the Regional Department of Agriculture (CRDA) in Medenine.

Figure 11. National Seminar participants: Béni Khédache, December 2004.

Figure 12. Discussion of the UNCCD local action plan with the farmers in the Béni Khédache region.

9.2 Communication and exchanges

- Dr Mongi Sghaier and Mr Mohamed Rahmani (Head of CRDA) participated in the International Conference on Water and Poverty which was organized by CIHEAM on 6–10 February 2006 in Cairo, Egypt.
- Some team members of the project (Khatteli, Rahmani, Sghaier, Ouessar, Fetoui, Boufelgha, Zammouri, and Abed) actively participated in the elaboration of the local plan for combating desertification and development (PAL-LCD) in the region of Beni Khédache, which covers a large area of the watershed studied. It was monitored by the Ministry of Environment and Sustainable Development with assistance from the German Cooperation Agency (GTZ).
- Most of the team members attended the UNESCO-sponsored International Conference on 'The Future of drylands' held on 19–21 June 2006 in Tunis; a key event in the International Year of Drylands and Desertification calendar.
- AJZ organized a one day workshop on the occasion of the International Day of Desertification (17 June 2006).
- Mr M. Ouessar and H. Taamallah undertook a scientific visit to the Department of Soil Care and Management at the University of Ghent from 15th August to 30th September 2006.

10. Research institution and team composition

10.1 Research institution

Institut des Régions Arides
4119 Medenine
Tunisia

10.2 Team composition

Team leader: Dr. Mohamed Ouessar, Water harvesting, IRA, Coord.

Team members

Research sub-team

Houcine KHATTELI	Desertification	DG of IRA
Houcine TAAMALLAH	Soil Science	IRA
Mongi SGHAIER	Agro--socio-economy	IRA
Azaiez OULED BELGACEM	Ecology and pasture	IRA
Dalel OUERCHEFANI	Remote Sensing	IRA
Hanen DHAOU	Bioclimatology	IRA
Nihaya OUNALLI	Agro--economy	IRA
Mondher FETOUI	Agro--economy	IRA
Naceur MAHDHI	Agro--economy	IRA
Hanène EL MELLAH	Hydrogeology	IRA

Partner research sub-team

Mounir ABICHOU	Olive production	Inst. Olivier - Zarzis

Development sub-team

Mohamed RAHMANI	Agro--economy	Head of CRDA-Médenine
Mohamed BOUFELGHA	SWC	CRDA-Médenine
Houcine YAHYAOUI		Hydrogeology CRDA-Médenine
Mongi CHNITER	SWC	CRDA-Médenine

NGO sub-team

Ahmed EL ABED, APB - Béni Khédache
Fadhel LAFFET, ASNAPED - Tataouine

Faical ZAMMOURI, AJZ - Béni Khédache
Habib BELHEDI, AAMTT – Tataouine
Mohamed DABBABI, ADD - Médenine
Kamel MADHI, UTAIM - Médenine

11. Publications as a result of SUMAMAD

Ouessar, M., A. Bruggeman, R. Mohtar, D. Ouerchefani, F. Abdelli, Boufelgha. M. 2007. Evaluation and impact assessment tools for water harvesting. Proceedings of the international conference 'Future of drylands', Tunis, June 2006, UNESCO, Paris.

Sghaier, M., M. Ouessar, M. Loireau, D. Leibovici, L. Bennour, M. Fetoui, M.A. Ben Abed, A. Ouled Belgacem, A. Tbib, H. Taamallah, E. De Laitre, R. Boukhchina, D. Ouerchefani & H. Dhaou 2008. Integrated environmental and socio-economic modeling using LEIS for desertification monitoring and assessment in the observatory of Menzel Habib (South Tunisia). In: *Proceedings of the international conference 'Future of drylands', Tunis, June 2006*, UNESCO, Paris [In press].

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Chniter, M. 2006. Etude de l'impacts des aménagements CES sur les inondations dans le bassin versant d'Oued Hjar (Médenine). MSc thesis, INAT, Tunis.

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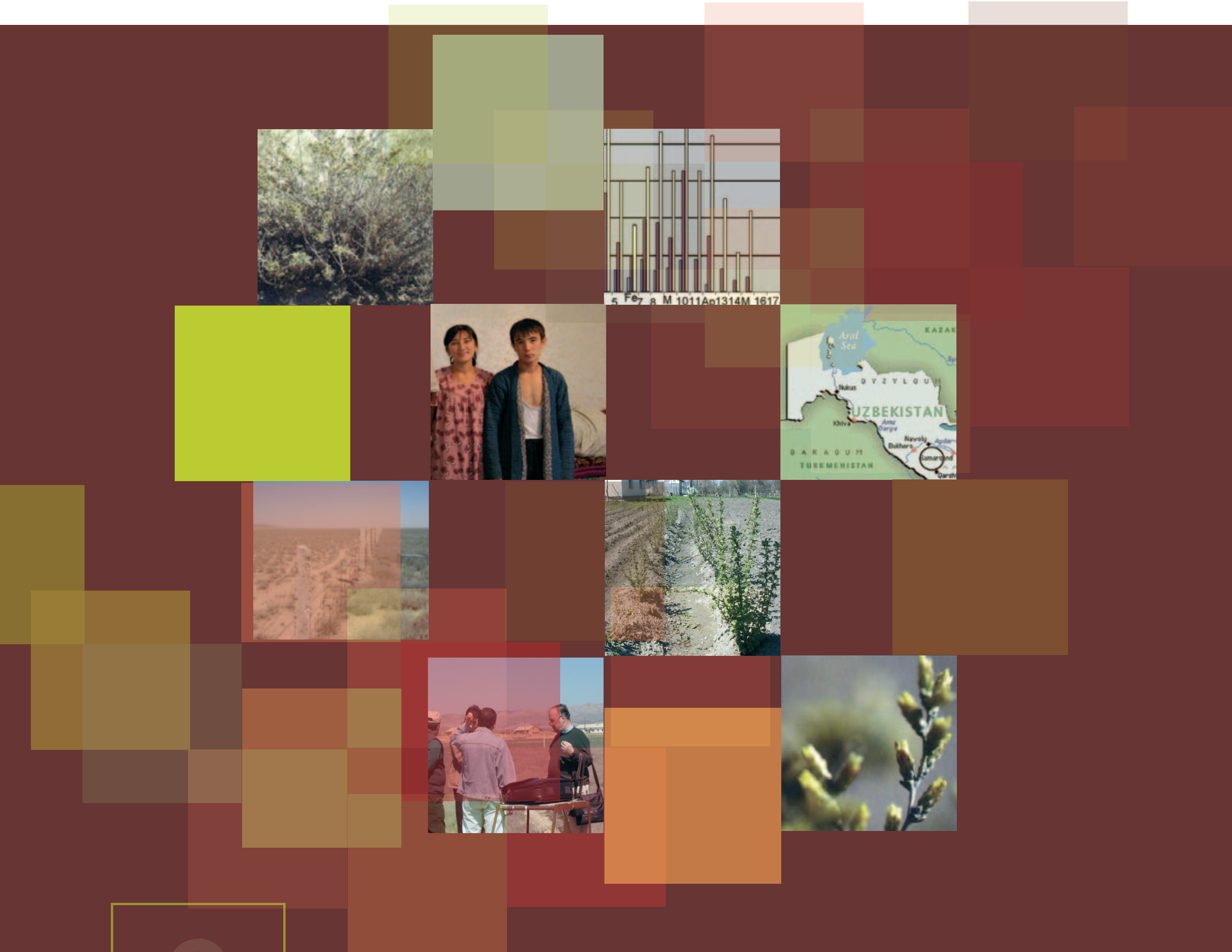

9

Karnab Chul

Uzbekistan

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1. Main dryland challenges at the project site

The republic of Uzbekistan is situated in the middle of the Eurasian land mass in the northern hemisphere between latitudes 37° and 45° N and longitudes 56° and 73° E (Gintzburger *et al*., 2003). It borders on five neighbouring countries: Kazakhstan in the north and the east; Kyrgyzstan and Tajikistan in the southeast; Afghanistan in the south; and Turkmenistan in the west.

Of the 447,400 km^2 land area of Uzbekistan, some 225,000 km^2 is used as rangelands and pastures for the *karakul* sheep industry producing the famous 'Astrakhan' pelts, and for goats, horse and camel breeding.

These rangelands are rich in medicinal and industrial plants, and represent 'hot spots' for the conservation of unique flora and fauna. However, the vegetation of these lands is under pressure due to an increasing need for food and feed. Overgrazing and uprooting of shrubs for fuel wood are particularly threatening the precious biodiversity found in these lands, and the livelihoods of the people who live there. Population growth and the associated expansion and intensification of agricultural activity in many areas of Central Asia has caused increased rates of land degradation.

As a result the region faces a serious challenge to its natural resource base. Croplands, rangelands and mountains are becoming degraded. The reduced availability of agricultural inputs, feed and fodder is resulting in a decline in livestock numbers. Water scarcity and misuse is compounding the threat to food security, human health, and ecosystems.

In order to contribute to food security, poverty alleviation and environmental protection in the Karnab Chul region, and in other dryland regions, the following is required: an increase in production, household income and welfare; conservation and a stop to natural resources degradation; an assessment of the current status of agro--ecosystems and the combined impact of technologies on ecological changes and the efficiency with which resources are used for increasing living standards at the levels of farm and collection of farms, village and a landscape.

2. Environmental characteristics of the study site

2.1 Location

The Karnab Chul is a steppe region located in the southern part of Uzbekistan, south of the Kyzylkum desert. It consists of gently rolling lowlands with elevations between 100 m and 500 m (Gintzburger *et al*., 2003). The area is surrounded by several major cities – Samarkand, and in a clockwise direction: Shakhrisabz, Karshi, Bukhara, Navoi and Kattakurgan (as illustrated by Figure 1). A research site with Bowen ratio and other meteorological equipment is situated in the centre of the region, near the village of Tim in the Nurobod district of the Samarkand province (WGS84 coordinates: 39°39'18.24"N, 65°46'40.32"E, 462 m above sea level).

Figure 1. Map of the Karnab Chul region *(source: Microsoft World Atlas, 1996).*

2.2 Climate

The Uzbek climate is predominantly continental and desertic (Gintzburger *et al*., 2003). This can be explained by its position in the middle of the Asian continent: the country is subjected to the influence of Arctic and Siberian fronts and at the same time there is no sea or ocean in the neighbourhood to buffer temperature variations. As a result, winters are very wet and cold, while summers are mostly dry and hot.

Temperatures are minimal in January and February and maximal in July and August (Figure 2). The difference between the mean daily maximum of the warmest month and the mean daily minimum of the coldest month (described by the continentality index, or M-m index, Gintzburger *et al*., 2003) is around 43°C. This is huge compared with lowland littoral zones which are characterized by an M-n index of 15–25°C, and confirms

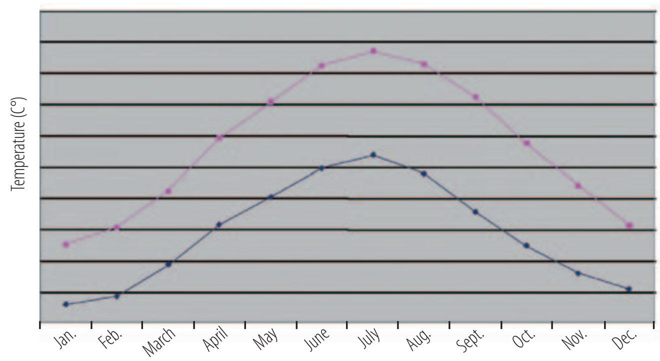

Figure 2. Average monthly minimum temperatures (line with diamonds) and average monthly maximum temperatures (line with squares) for Tim, according to data from the FAOCLIM database *(source: New_LocClim, 2005).*

the continentality of Uzbekistan. It is usually only in April that the mean monthly minimum temperature rises above freezing point and where the mean monthly maximum temperature is high enough to enable plant growth; mean minimum temperatures fall again rapidly to below 0°C by mid October (Gintzburger *et al*., 2003). This limits the growing season to the period April-October (Figure 3).

The rainfall pattern is monomodal: most of the precipitation falls in the winter and the spring. The main annual precipitation (MAP) depends on the region, with less than 100 mm in the Kyzylkum desert and around the Aral Sea, increasing to 200 mm in the Karnab Chul region, and reaching almost 700 mm in the eastern mountains where they rise over 2000 m. A low inter-annual variability exists, especially in the low precipitation zones, where coefficients of variation range between 27 and 34 % (Gintzburger *et al*., 2003). This explains the great stability of the rangeland production systems in Uzbekistan. The drought and high temperatures in July and August are limiting factors for growth during these months.

The dominant wind in the Karnab Chul region blows from the east in the winter where it is predominantly northerly during the summer months. The last often brings a fast (6-10 m/s) hot, and dry air stream with dust and sandstorms to the country (Gintzburger *et al*., 2003). There is no doubt that these hot windy conditions increase the mean

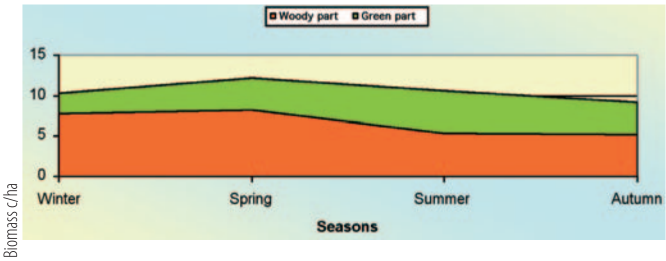

Figure 3. Seasonal dynamic of biomass of the *Artemisia* annuals semi desert rangelands on foothills (Karnab 2004-2006)

annual temperature, potential evaporation, and the risk of erosion, and that they damage crops and fruit trees.

The evapotranspiration (ET) pattern is also monomodal: the combination of high temperatures, low relative humidity, high solar radiation and windy conditions result in extreme potential evapotranspiration (ETo) rates for the summer months however much lower rates may be expected in the winter. Values for the Karnab Chul region range between 230 and 340 mm/month (7.5–11 mm/day) in June, July and August – dependent on the source. November, December, January and February are characterized by an average ETo of 45 mm/month (1.5 mm/day). Figure 3 illustrates how rainfall relates to potential ET in the Karnab Chul region. The dominant part of rainfall comes in late autumn and winter periods of the year and higher amount of evapotranspiration occur in summer periods, where no precipitations take place.

2.3 Soil

The desert soils of Uzbekistan are characterized by low organic matter (less than 1 %), a high level of calcium, are often associated with gypsum and have a low agricultural potential (Gintzburger *et al.*, 2003). They are frequently saline and alkaline, have poor structural characteristics and often a high level of compaction. Three main groups may be distinguished:

- Sandy aeolian soils (for example the sand dunes of the Kyzylkum)
- Solonchak, solonetz, and takyr (for example in situations with a high saline water table, like on the shores and banks of lakes and rivers)
- Serozem soils (for example on the steppe)

The Karnab Chul region mainly consists of this last group of soils. The serozem (Calcaric Cambisol, according to the WRB soil map [World Reference Base for Soil Resources] and Driessen *et al.* (2001), is the grey-brown semi-desert soil, typical for arid steppes. The soil is always alkaline and has a very low organic matter content (< 0.5 %) and C/N ratio (5-6). The texture is mostly sandy-loam to loam, and the carbonate content increases with the soil depth (Gintzburger *et al.*, 2003). However, the serozem of Uzbekistan does not develop deep calcareous, gypseous hardpans or any form of underlying crusts; this may be due to the colder winters (compared to the North African serozem).

2.4 Vegetation and wildlife

The flora in Uzbekistan is extremely rich and is represented by more than 3,100 species of vascular plants, of which 366 are endemic (Gintzburger *et al.*, 2003). The most common families are: *Asteraceae* (Compositae), *Fabaceae* (Leguminosae) and *Poaceae* (Gramineae). The richest genera are: *Astragalus* (Fabaceae), *Cousinia* (Asteraceae) and *Calligonum* (Polygonaceae). Also *Artemisia* (Asteraceae) is a genus with many species.

The *Artemisia* genus is strongly associated with the Karnab Chul steppe where *Artemisia diffusa* appears to be the dominant species (Figure 4). *Artemisia diffusa* is a chamaephyte – a dwarf shrub (30–50 cm height) with its surviving buds close to the aboveground level. It is a perennial shrub with a life span ranging from 7 to 25 years. Its strong, pivotal root penetrates to a depth of 1.1–2.5 m. The vegetative cycle takes place from the end of February to the beginning of June. Its reproductive cycle completes during September to November after a summer rest when eventually spring leaves may fall off. Seeds are dormant and viable for more than two years. *Artemisia diffusa* is a xero-gypsophyte, which is also frost-resistant. Maximum edible biomass becomes available from September to November. The shrub provides a valuable fodder bank during the autumn-winter feed gap. Typical yield on natural pastures varies from 0.1 to 0.25 t/ha.

Range degradation caused by overgrazing, cultivation or fuel wood collection has not only lead to a formation where *Iris songarica, Cousinia resinosa* and *Girgensohnia oppositiflora*, which are poorly palatable, have replaced *Artemisia diffusa* as main contributors to the range biomass, but also to an increase in wind and water erosion.

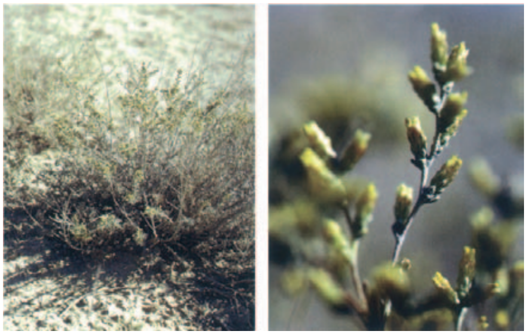

Figure 4. *Artemisia diffusa* shrub and its inflorescences.
(source: B. Mardonov, 2003).

Genus and species	Family	Uzbek name	Plant form	Use
Amigdalus nana	Rosacea	Bodom	Small tree	Fuel wood and nuts
Artemisia diffusa	Compositae	Shouvok	Shrub (10-30 cm)	Summer and fall grazing/wood
Ziziphora tenior	Labiatae	Kiik ut	Annual medicinal	Medicinal/tea
Cousinia resinosa	Compositae	Karrak	Annual thistle	winter feed
Poa bulbosa	Gramineae	Konghur bosh	Perennial grass	Winter and spring grazing
Carex pachystylis	Cyperaciae	Rangue	Perennial	-
Alhagy pseudoalhagy	Leguminosae	Yantak	Shrab	winter feed
Ferula assa-foetida	Umbreliferae	Kavrak	Annual	winter feed
Peganum harmala	Zygophyllaceae	Hazorispan or isfant	Perennial poisonous	Fumigation
Iris songarica	Lilliaceae	-	Perennial poisonous	-
Haloxilon aphyllum	Chenopodiaceae	Saxaul	Tree	Fuel wood/ grazing
Aegelops truinciallis	Gramineae	-	Annual grass	Grazing
Acantophyllum borszczowii	Caryophyllaceae	-	Perennial	
Ceratocarpus arenarius	Chenopodiaceae			
Tortulla desertorum	-	-	moss	
Scabiosa oliveri	Dispsacaciae	-	Annual	
Salsola praecox	Chenopodiaceae	-	Annual	
Diarthon vesiculosum	Thymeilaeceae	-	Annual	

Table 1. The main vegetation species.

The fauna of the Karnab Chul region is diverse. Reptiles include lizards (toad agama, monitor lizard, gecko) and snakes (viper, gourza, Central Asian cobra). Among the large mammals, goitered gazelle and saigak are particularly important in terms of conservation. Jackals, wild boar, honey badger, wolves, foxes, porcupines, badgers, and hedgehogs dwell in the plains and foothill areas. The rich diversity of bird life includes eagles, jackdaws and kites.

2.5 Hydrology

The territory of Uzbekistan is drained by two major rivers: the Syr Darya and the Amu Darya. The Syr Darya rises in the Tian Shan mountains (Kyrgyzstan) and finds its way through the Ferghana Valley in the east, completing its journey of 2,000 km through the southern part of Kazakhstan to the Aral Sea. The Amu Darya originates from the Hindu Kush/Pamir mountains (Afghanistan/Tajikistan) and follows the western border of Uzbekistan, thereby separating the Karakum desert (Turkmenistan) from the Kyzylkum desert (Uzbekistan) before it ends up in the Aral Sea. Of the thousands of smaller streams crossing the country, the Zerafshan River is the most important. It also has its source in the Pamir mountains of Tajikistan, and waters the oases of Samarkand and Bukhara before it dries out in the Kyzylkum desert. The hydrologic situation of Uzbekistan is illustrated in Figure 5.

For several hundred years the Aral Sea was once the fourth greatest lake on earth, but due to an increase in irrigation for cotton monoculture within the basins of the contributing rivers since the 1950s, the Aral Sea has begun to disappear (Matsuura, 2000). The lake level has dropped 17 meters during the period 1960–1992, the area of the Aral Sea has halved and its volume has quartered (Macleod and Mayhew, 2004). The main consequences of the shrinking Aral Sea are:

- Negative changes in the microclimate in the vicinity of the lake (dust-salt storms, greater temperature extremes, etc.).

Figure 5. Hydrologic situation of Uzbekistan. The Karnab Chul region is encircled in black. *(source: Microsoft Encarta, 1995).*

- Complete loss of the economical importance of the lake (fishing and navigation has disappeared).
- Elimination of agriculture from large areas in the deltas (due to insufficient freshwater and the increasing salinization of the soils).

No major river crosses the Karnab Chul region, which mainly depends on the scarce precipitation for its water supply. The nearest rivers are the Zerafshan in the north and the Amu Darya with its irrigation channels in the south. The ground water table is located deep below the soil surface (30 meters).

3. Socio-economic characteristics of the study site

The socio-economic characteristics are an integral component in assessing the productivity, efficiency and feasibility of improved production and resource management options, and help identify potential constraints to their adoption by smallholders. Socio-economic assessments can detect changes in land resources policies, population pressure and socio-economic status, over

historic and modern time, for comparative analysis with indicators of land degradation.
Socio-economic information collected during the study years were shaped into the following:

- Family composition and structure: identifying those members involved in livestock production and income-earning activities.
- Livestock ownership.
- Grazing rights and land tenure conditions.
- Tax and government quota commitments.
- Income and priority of use of any surplus cash.
- Attitudes to livestock and elements of the landscape, particularly those that preclude use.
- Perception of the condition and trend of the livestock and grassland resources.
- Ideas of practicable development opportunities and how they might be implemented.

Some data were completed in a long-term base so as to compare trends during recent years. Observed trends in socio-economic information mainly occurred due to changes in the environment and society.

Uzbek families are large in size both in terms of members and the territory where they live. The average family size can vary from 7–8 up to 12–13 persons. Parents with several sons and their families live together for some years. They all share a common house, kitchen facilities etc.

Adult members of the given family are usually externally employed mainly in the towns and cities. They spend most summers working outside their living area to make money. The dominant part of the local population consists of people aged 15–64 years; they represent about 61.1% of all people living in the research area. Children between 0–14 years of age represent 34.1%, and only 4.8% of the population is over 65 years.

Initial data processing showed a positive increase in the number of small ruminant animals during the last two to three years. The total number of animals increased up to 65,000 in 2005 as compared to 40,000 in 2002. This increase comes together with increasing numbers of herds in a given area. Unfortunately, the proliferation of smaller herds, in addition to the greater number of herds, has negatively affected the grazing strategy in the region. It is a Uzbek tradition for fathers to split their herd when their sons establish their own families. For example, if a father has five sons and possesses one herd of 100 animals, he will split his herd among his sons resulting in five herds each with twenty animals. The farmers still have no notion of marketing, processing and trading pelts. Therefore they are all more interested in keeping lambs for fattening and only consider adult animals as having value. These animals are considered as a form of deposit and can be cashed at any time or bartered for other home use products. Consequently, the total number of animals has increased and pressure on natural resources has also increased.

The second step should be the investigation into the increasing of numbers of animals in a herd for an optimal grazing strategy. A small number of herds can bring greater potential to the shared utilization of scarce resources in the rangelands. At the same time the farmers can deal with in-depth processing of existing resources and different income-generating activities.

In the process of socio-economic data collection it was possible to monitor the location of animals near twelve of the deep-water wells. It was observed that once during the day all the animals made their way to drink from the wells and return to graze after noon. In this way, the grazing traffic for all the herds was satisfied. The information on the main migration routes will be used to develop an optimal migration strategy of the animals in the region.

The structure of the herds also changed due to the increase in the number of goats. Some farmers prefer to keep a greater number of goats in the harsh area than sheep. Data was recorded on the location of all the animals by ownership. We obtained information on sixty farmers who owned all their animals. The farm size varied both in numbers and structure. Some farmers have more than 1,000 collectively owned animals and some have only 200. The structure also varied in terms of the composition and ratio between rams/ewes. Additional information on each type (cattle, sheep, goats, etc.), the age and sex composition of each herd, and the historical livestock population statistics representing as many years and livestock types, were recorded for further analysis.

4. Conservation of natural resources, community development and scientific information

4.1 Traditional management

Before the Soviet revolution, the desert livestock industry, and Karakul sheep breeding in particular, was based entirely on rangeland forages and resources. Hand feeding was carried out only in special cases such as in breeding or in the case of frail animals. The system was basically self-sufficient, i.e. it did not rely on imported inputs. The traditional pastoral industry consisted principally of breeding sheep (i.e. Karakul and Gissara sheep) and camels, in addition to horses and cattle. The major outputs were meat, wool, pelts (for example the famous 'Astrakhan' pelts), carpets and milk.

In search of the best forage, pastoralists moved short distances from one place to another depending on the availability of forage and fuel wood. They also traveled long distances to take advantage of the valuable forage of the different types of winter and summer vegetation as well as vital water supplies for their herds. This also allowed them to minimize feed storage (Gintzburger *et al*., 2003). In winter, the *chol* (marginal drylands) was preferred as animals could graze and shelter between the sand dunes. In the spring, pastoralists moved their herds in the direction of the *adyr* (foothills) where nutritious food and plenty of water in wells and watering points were available for pregnant animals. During the summer and autumn months, they climbed as high as possible into the mountains to escape the high temperatures and drought of the plains. With the approaching winter, when the first snows and frosts arrived, they gradually returned to the lowland and the sandy desert. Thanks to the constant movement of herds, the problems of overgrazing and rangeland degradation were still non-existent.

4.2 Rangeland under collective farming

Nomadic movement between the different ecological zones ceased at the time of collectivisation in the 1930s thus altering and marginalizing the livestock system in Uzbekistan. However, the benefits of the long migrations and the movement of herds were recognised and re-established by allocating appropriate grazing land in the different ecological zones to the *sovkhozes* (state farms) and *kolkhozes* (collective farms) (Gintzburger *et al*., 2003).

With the centrally planned socialist system in place, production of Karakul sheep increased (after a radical decline in animal numbers during the first years) due to the rapidly growing population of sheep together with the demand for livestock products, pelts and wool, and because pelt prices were also rising fast. Greater production could only be achieved by improving the sheep breeding strategy and fertility, and through the introduction of intense feeding systems. As a matter of fact, the supplementary feeding, together with the already mentioned large-scale movement of animals, offset the previously existing natural controls that prevented the rapid expansion of herds such as the massive numbers that died during severe winters and droughts, and this therefore contributed to a gradual increase in animal numbers.

However, as a consequence of the increased demand for fodder, large parts of the better rangelands were ploughed up and reserved for animal fodder production (i.e. the barley grown was used as fodder). Even greater areas of rangeland was destroyed and used for irrigated cotton monoculture when the Soviet planners assigned Uzbekistan as the main cotton producer of the USSR. This resulted in the first visible signs of rangeland erosion and degradation.

4.3 Current situation

In 1991, Uzbekistan declared its independence and became a member of the CIS (Commonwealth of Independent States), together with four other former republics of the Soviet Union: Kazakhstan, Kyrgyzstan, Tajikistan and Turkmenistan. The transition process following independence including adaptation to a market economy and private ownership of production factors (although rarely land), involved dramatic reductions in agricultural stocks and productivity (Gintzburger *et al*., 2003; Nasyrov, 2004).

One of the major consequences of decollectivization is the increased risk for farmers who no longer benefit from protection against calamities (such as drought, severe winters and sandstorms) from the collective farm, or the state in general, through buffers as feed imports and social security. Also, the systems concerning production and processing of livestock products, breeding and feeding, which were developed for large state farms, may no longer be appropriate for use in small private farms, also because certain technologies are no longer available. Moreover, agricultural education was never aimed at farmers but was focused instead on creating specialists such as tractor drivers or cotton pickers. New farmers therefore have limited experience in production, and their experience in processing and marketing is generally non-existent.

As a consequence of reduced access to energy, people started to uproot plants for firewood. In addition, many species of the *Artemisia* rangelands are harvested for medicinal purposes. A lack of input (such as equipment and fuel), together with increased input/labour costs and incorrect policy making, has lead to a situation of reduced mobility whereby farmers cannot always afford to take their animals to distant rangelands, even if they wish to do so. As a consequence, grazing pressure has increased; animals are kept at higher density for longer periods on the same areas of land, espe-

cially around settlements and wells. In these areas, overgrazing has become a major problem as natural vegetation has no opportunity to re-grow and re-seed, and this provides an advantage to tougher – often less palatable – vegetation, and in any case, results in the decline of plants species diversity, increased erosion and thus reduced soil fertility. Vegetation in remote areas becomes woodier due to low grazing, and when woody parts begin to dominate, risk from fires becomes a serious consideration.

5. Practices implemented for soil and water conservation, especially in rangelands

Due to population growth and other factors, described above, there is an increased demand for grain and meat in Uzbekistan, although there is still a need to balance both wheat and animal production with the available natural resources in order to secure the future of agriculture in Uzbekistan (Gintzburger *et al*., 2003). The farming system in the study area is still under transition. The majority of domestic animals are found in small herds that roam near deep-water wells or villages.

Several combinations of traditional knowledge together with modern technologies were applied to influence rangeland development. The first step, which was not so easy to achieve, involved convincing farmers to merge their animals into reasonably sized herds in order to share grazing and processing of the obtained products. They would still have the same number of animals but would pay for shepherding on a per animal/monthly basis. In this way, it was possible to reduce the number of herds per area and increase the number of animals per herd, which provides an opportunity for better management. One

Figure 6. Rows of small nurseries

person could take care of a herd comprising 25–350 animals; another could perform other duties such as winter reserve fodder preparation, the processing of pelts, re-seeding of degraded rangelands etc. Several large-scale herds were composed in the study area. A comparison of productivity between small and large-scale herds showed several benefits with the new modelled ones. It did reveal several promising options such as an improvement in breeding, health, and the rational use of range resources.

Another experience involving the coupling of traditional knowledge and modern technologies consisted of organising simple breeding techniques. Farmers were trained on the initials steps of breeding such as screening for better features, identifying healthy animals, artificial insemination, and weaning young lambs for further feeding. One experienced farmer received hands-on training from leading experts and scientists on small ruminant breeding, and now they are responsible for all routine work. They posess all the records on the health status of animals, their locations and productivity, and will provide initial consultancy during the insemination period in late October to all members of the newly established association. All data regarding the animal's condition, breeding character-

Figure 7. *Atriplex canescens.*

istics and wool structure, which can be used later for breeding, is compiled into a database.

There is a great need for reliable data to assess the constraints and possibilities (in terms of carrying capacity and productivity) of the rangelands, which can be obtained by Participative Rural Appraisals (PRA), field monitoring and expert opinions; tools such as Geographic Information Systems (GIS) and modelling can also play an important role. A solid database containing several layers of spatiotemporal information on the current situation on rangelands was created. This database will be used for further analysis using modern analytical tools. During this work, farmers were also trained on the initial steps of monitoring range degradation. Dominant plant species and their invasive competitors, such as weeds, were shown to them during a field survey. The main indicator plants, which show a degree of degradation such as *Peganum harmala* and *Iris songarica*, were chosen to train farmers to detect the occurrence of degradation at an earlier stage. Simple techniques of counting these plants per square metre can demonstrate stages of degradation. In this way, farmers can detect changes before they spread over a larger territory.

The improvement and rehabilitation of rangelands, through the creation of long-term artificial range and pasture, can be realised by direct seeding of native tree/shrub species (*Haloxylon* and others). Without soil preparation, and following a light snowfall in the winter months, sheep then trample the sown area to pit the seeds into the soil. Small-scale nurseries were established in the different zones to show farmers how to better grow fodder plants. Small size (5x5m) protected paddocks in severe degraded areas were left to allow dominant plants to form mature seeds and disseminate to other areas for re-seeding. Populations of arid fodder plants (about 25 species) from families of Chenopodiaceous, Fabaceae, Compositae and Graminae were distributed on the territory of Uzbekistan, and patterns of perennial *Atriplexes*, obtained from Syria and Tunisia, were used to prepare transplants. Laboratory investigations on collected seed quality were carried out at the greenhouse facilities at Samarkand University as well as on-farm conditions. The revegetalization of saline and degraded lands requires a preliminary preparation of the soil, an improvement in hydrological conditions, and careful selection of plants. During a special demonstration workshop, farmers were introduced to simple techniques for revegetating transplants. The main emphasis was placed on choosing simple, affordable and low cost techniques for such work. A special demonstration plot was established as a research station for the environmental testing of promising fodder plant varieties.

The most valuable technique for the establishment and rehabilitation of shrub rangelands of the Karnab Chul region appears to be the reseeding of native range species and the creation of sown pastures. Some benefits can be obtained by range improvement through the creation of pastoral shelters, windbreaks and tree belts of *Haloxylon spp*., *Calligonum spp*., *Pinus eldarica* and other tree-like species used for erosion control and the reclamation of severely disturbed sites. Due to their low seed germination and/or the destruction of seedlings at an early stage of root fixing, it would be reasonable to apply the vegetative method for their reproduction with the subsequent transplantation of seedlings on degraded sites.

Some of the actions undertaken by the government to guide farmers towards a more sensible use of rangelands are given below: subsidies on inputs (for example fuel, water, fodder and drugs) and investment on infrastructure will raise possibilities and the intention to move herds from one ecological zone to another; trading regulations on livestock products and protection of livestock processing industries (wool processing into carpets, souvenirs and handicrafts; milk derivatives; flower culture) will help create additional incomes for the farmer; the development of alternative energy facilities, particularly in the Karnab Chul steppe with its uniform and rich solar and wind energy resources, may result in decreased firewood harvesting and thus a decrease in rangeland degradation (Nasyrov, 2004).

6. Income-generating activities to diversify the economic base at the household level

This part of the project was the most interesting in terms of the integral role it plays in generating income where the potential of all the family members can be realized. It lies between rational utilization of natural resources and housekeeping in its largest sense.

It is important to increase sheep production and improve the quality of processing and product conservation. For these reasons, the processing of sheep products – meat, wool and karakul pelts – is important in the emerging farming systems. It is therefore necessary to carry out research to create new processing and preservation technologies that are adapted to these new farming systems, which will in turn increase revenues.

Sources of additional income in the study area include:

- wool processing (carpets, souvenirs, handicrafts, home utensils, etc);
- milk derivatives;
- raising of ostriches;
- flower culture (seeds for essential oils as a raw material for perfume and pharmaceuticals).

Income-generating activities consist of different activities directed towards the realization of the unique potential of dryland areas. It may consist of processing different by-products, field activities, manufacturing of handicrafts and so on. These activities are mainly directed to the employment of women and children with the appropriate labour skills.

We attempted to analyse the current situation of female employment and to find a solution for their employment needs. Women working at home can keep on eye on their children while at the same time ensure their further education. Conversely, children tend not to receive adequate care when their parents are unavailable and away from home.

With this in mind, we chose to introduce small-scale carpet production, which could be carried out by female family members at home, and at the same time allows women to demonstrate their skills in front of the community. The small-scale carpets are in demand from local and foreign tourists and can replace huge, large-scale carpets in the tourist market. Following the initial groundwork, we chose a number of pilot sites. Active community members were involved in professional training and commenced their activities. This kind of activity also solved the many problems encountered in marketing wool from Karakul sheep. For many years this product provided an additional income to the household but due to the drop in quality, it began to lose value and market share. In addition, due to the environmental conditions, wool from Karakul sheep has a lower spinning quality. We experimented and dissolved several organic compounds from wool to make it softer rendering it suitable for carpeting. Several detergents including gasoline, dishwashing liquid, and oily hair shampoo were tested as solvents of the different organic compounds. During this work it was possible to isolate and purify several organic compounds (lanoline), which could be used later in pharmaceuticals and the perfume industry and at the same time render wool softer and gentler for spinning. The amount of isolated compound from each kilogram of wool was relatively low and varied between 0.25–0.45 g, however it can be obtained using simple techniques under modest conditions and is an additional family income. People were very proud of undertaking this work and there is hope that several young attendees will continue with their education and continue to process agricultural by-products.

The second part of the income-generating activities involves soap production. It also has the potential to increase family income by producing attractive products for the tourist industry. Several types of soap made from local ingredients were tested both in terms of simplicity of production and labor costs. The region is within reach of many species of medicinal and essential oil plants, which in the case of optimal utilization can be considered as essential ingredients in soap production. Several training workshops were conducted at the research site to demonstrate modest, affordable technologies of soap production. Moreover, these new technologies are not new to the region. The most important part of soap production is the alcohol/alkaline solvent, which is used at a rate of 0.5L per 0.5 kg of end product. The rest (fat, oil, ash) is widely available. Essential oils from arid plants serve both pharmaceutical and perfumery purposes. In order to attract tourists, the soap was shaped into different historic monuments. The different coloured and shaped soap bars were displayed at a tourist hotel in Samarkand in the way of a small exhibition.

Ecotourism can be considered as another form of income-generating activity for local people. The Karnab Chul area is rich in natural beauty and geological wonders and is home to a wealth of plants and wildlife, and dotted with historical sites. Tourism is a source of income but it must be carefully controlled as over-development can eventually degrade the environment. Careless use of resources in such vulnerable areas can be self-defeating as the environment is the very source of initial tourist attraction.

Nature-oriented tourism is not new in Uzbekistan. However, if ecotourism is defined as tourism structured to facilitate the objectives of conservation and/or sustainable development, then there is no history of ecotourism in Uzbekistan. Hard currency touting of foreign tourists, organized by private and government organizations including State Nature Protection Committee and State Forest Committee employees, illustrates the tone of nature tourism in Uzbekistan today.

A special website on natural and historic monuments was prepared and an initial database for tourist sites as well as part of an Archeological Information System (AIS). Two main attractions such as the thousand year old *Juniperus zaravshanica* tree and the Samonides mausoleum were included in this system.

Vegetable and ornamental plants cultivation attracted a lot of interest from the local people. A distributor of vegetable seeds from the Netherlands kindly donated twenty boxes of tomato and cucumber seed to our project. These materials were distributed among four families interested in growing vegetables under artificial nursery conditions. The low cost of production was achieved due to the absence of heating and insect control measures. Plastic covers were cheap to set up and at the same time maintained optimal and constant humidity inside, which had a positive effect on fruit formation. This technology was new to local farmers and they were all happy to share this knowledge with each other. The choice of better varieties of vegetables is still under investigation.

The botanical garden of Samarkand State University was also involved in one of the income-generating activities. Greenhouse facilities were used to prepare seedlings of exotic shrubs, trees and flowers for growth under plastic housing in the Karnab area. The rootstalks of olive and cypress trees were distributed to several families to grow until maturity. All the distributed specimens reached 3–4 years age and are in good marketable condition. Each tree will provide a solid income to the family, and is equivalent to the price of lamb. Flower culture is a next phase of greenhouse diversification and production, which will bring employment to the community during the winter.

All these activities could be administered in similar regions to provide employment to local people and therefore provide a steady family income. It is important to note that people can carry out these activities under house conditions using modest technology and local materials. The diversification of income-generating activities will have a positive economical and environmental impact, which will be realized with respect to sustainable development regionally. The list of economically efficient income-generating activities is not yet complete; several additional activities are still under investigation. Dried fruits preparation, origami toys, higher quality seed production, essential oil extraction, and apiculture are all subjects for further investigation in the region.

The economic efficiency and incomes of small farmers could be significantly improved if post-harvest management, storage and processing of crop and livestock products were improved and better oriented toward market opportunities. Research is needed to inform policy makers of the benefits of appropriate investment in processing and post harvest technologies, which include increased income for producers (value added), increased employment, and increased national income from exports.

7. Results obtained

7.1 Deep-water wells

All field measurements and observation were mainly conducted near the deep-water wells. The coordinates of the twelve principal deep-water wells were recorded by GPS for further georeferencing (Table 2). These wells are considered principal points for all related measurements. The surrounding area beside each well has a concentric shape of degradation. The coordinates for all rings showing stage degradation were recorded. On the basis of this data we can calculate the stage of degradation (lower, moderate and severe) of the area.

7.2 Biomass production

The long-term observation of biomass production showed a decline in the productivity of dominant plants over the last two seasons. This can be attributed to the increasing number of domestic animals per grazing area.

Farmers are keen to keep animals for fattening, and Karakul pelt is still not in high demand, the increased number of animals therefore has a negative impact on vegetation cover dynamics. A comparison of ground measurements of biomass production with satellite data calculations revealed a close positive correlation in the seasonal trend, and demonstrates a great potential for using remote sensing techniques in the future. This

N/N	Measured points	Alt. m	Coordinates N	E
1	Tim (BR - station)	468	39.65	65.39
2	Sahoba	308	39.60	65.53
3	Tutli	320	39.68	65.48
4	Tutli (Research area)	329	39.66	65.51
5	Koshara near Sahoba	328	39.64	65.52
6	Uzunkuduk (Border Sahoba-R.Jahongirova)	355	39.60	65.66
7	Tukkiztula	426	39.65	65.70
8	Tukkiztula well	422	39.64	65.69
9	Garden near Tim	451	39.64	65.74
10	Etikkuton	452	39.65	65.83
11	Energoraspredelite	486	39.62	65.95
12	Seprki	467	39.45	65.55

Table 2. The coordinates of the twelve principal deep-water wells.

approach can provide valuable information over the large area in a comparatively short time period.

7.3 Soil data

The soil data collection group gathered information on the current status of the related soils. The soil cores were taken from the different sites to describe agro–chemical, agro–physical and biological features. The 137Cs tracer technique was used to calculate land degradation attributed to the deflation process. Soil samples were taken according to a procedure developed by Prof. D. Walling. The main part of this technique is to describe the distribution of 137Cs along the soil profile in comparatively different landscapes or degradation areas. The profile 137Cs content data can be used as important input data for two models such as USLE (Universal Soil Loss Equation) and RUSLE (Revised Universal Soil Loss Equation). These models are used to calculate degradation in a given region due to deflation. A large database on 137Cs was prepared under the guidance of Prof. Walling during his mission to the research area. Prof. Walling gave a brief training on soil sampling, analysis and statistical processing of obtained data. These data will also be used as a layer of a proposed electronic atlas of the Karnab Chul area.

7.4 Rehabilitation of rangelands

The populations of arid fodder plants (about 25 species) from Chenopodiaceous, Fabaceae, Compositae, and Graminae families distributed throughout the territory of Uzbekistan, and patterns of perennial *Atriplexes* obtained from Syria and Tunisia were used to prepare transplants. Laboratory investigations on collected seed quality are ongoing at the greenhouse facilities of Samarkand University as well as on-farm conditions. The revegetalization of saline and degraded lands requires a preliminary preparation of the soil, an improvement in the hydrological conditions, and a careful selection of plants. In a special training demonstration workshop farmers were introduced to simple techniques for the revegetation of transplants. The main emphasis was placed on choosing simple, affordable and low cost techniques for such work. A special demonstration plot was established as a research station for environmental testing of promising fodder plant varieties.

The most valuable technique for shrub establishment and rehabilitation of rangelands of the Karnab Chul region appears to be the reseeding of native range species and the creation of sown pastures. Some benefits can be obtained by range improvement through the creation of pastoral shelters, windbreaks and tree belts of *Haloxylon spp., Calligonum spp. Pinus eldarica* and other tree-like species used for erosion control and reclamation of severely disturbed sites. Due to their low seed germination and/or destruction of seedlings at an early stage of root fixing, it would be reasonable to apply the vegetative method for their reproduction with the subsequent transplantation of seedlings on degraded sites.

7.5 Ecological status of research area

To better understand the role of rangelands in global carbon cycles, measurement of CO_2 flux between the surface and atmosphere was continued. Four specific questions were targeted in order to provide answers to this project:

- What role do Central Asian rangelands play in the carbon cycle? Are they a sink for atmospheric CO_2?
- Is CO_2 flux correlated to climatic or ecosystems factors? And are the relationships strong enough to allow extrapolation?
- What influence do land management activities (such as grazing, conversion into croplands, firewood collection) have on rangeland CO_2 flux?
- Do direct measurements of CO_2 flux provide an accurate assessment of primary productivity?

The Central Asian Region is dominated by vast rangelands and it was hypothesized that these extensive rangelands may constitute a significant portion of the 'missing sink' that attenuates the increase in global atmospheric CO_2. The capacity of rangelands to sequester atmospheric CO_2 could be increased with better rangeland management practices, thereby improving the welfare of small landowners and, if acceptable treaties and protocols can be developed, possibly providing opportunities for trading 'carbon credits'. Daily and seasonal carbon balances of rangeland ecosystems were measured with a Bowen ratio (BR) technique that calculates net CO_2 exchange between a terrestrial surface (including soil and vegetation) and the atmosphere. On the basis of field and laboratory investigation, predictive models for carbon flux and aboveground net primary production in the major types of rangelands covering significant areas of Central Asia were developed. The installation of two automatic recording weather stations in the study area provided real-time data, such as rainfall, temperature and wind speed. This information proved valuable in forecasting the rainfall-biomass relationship, so it provides an opportunity for range users to determine potential grazing sites and make an estimate of the amount of forage that will be produced following rainfall.

7.6 Assessment of productivity under various grazing intensities

Three different methods were applied to estimate productivity of rangelands so as to develop a methodology to up-scale obtained results into larger areas: plot sampling method, Bowen Ratio Energy Balance (BREB), and a soil water balance model. A brief introduction of each method is given below.

7.6.1 Plot sampling method

Monthly (green and woody) biomass figures for the area around Tim and Tutli in the Karnab Chul region were measured on a monthly base at different locations. Not only shrub density and weight, but also ground cover [%], shrub height [m] and diameter [m] were observed. Ground cover is measured by dividing the cumulative horizontal length of shrubs crossing the long sides of a plot by the total length of these sides.

Plots are marked out in grazed areas, while the research site with meteorological equipment is surrounded by a fence making it inaccessible to sheep and goats: meteorological parameters, for example evapotranspiration (ET) rate, are measured above a non-grazed canopy.

7.6.2 Bowen Ratio Energy Balance

The Bowen Ratio Energy Balance (BREB) gives the basis of an indirect method to estimate productivity. The formula consists of only three variables representing four micro-meteorological parameters, which have to be measured, and is able to predict ET rate of a canopy and thus gives an idea about yield, if a water productivity function is used to link ET with productivity.

Only 4 meteorological parameters have to be measured for Bowen ratio based ET estimations: air temperature gradient (äT), water vapour pressure/concentration gradient (either äe or äw), net incident radiation (Rn), and soil surface heat flux (G).

Both gradients in air temperature and water vapour pressure/concentration are measured by sensors mounted on two sensor arms, vertically separated from each other by a distance z, within 3 metres above the canopy. Air temperature can be obtained by a thermocouple; water vapour concentrations are measured with an infrared gas analyser (IRGA), which analyses air samples from two heights, while water vapour pressure can be calculated from relative humidity and temperature (Allen *et al*., 2004):

$$e = \frac{e^{\circ}(T)\,RH}{100}$$

Where:
e = water vapour pressure [kPa]
e° (T) = saturation vapour pressure at temperature T [kPa]
RH = relative humidity [%]

Net radiation may be obtained electronically by a net radiometer. Soil heat flux at the surface is difficult to measure but is estimated based upon knowing certain soil characteristics and the measure of heat flux at some depth below the surface: several sets of heat flux plates, thermocouples and soil moisture probes are used for this purpose. Heat flux plates, buried in the soil, measure vertical flow of energy through the soil. The heat flux at the surface is then calculated by adding the heat flux measured by a plate to the change in energy stored in the soil layer. This storage term is calculated by multiplying the change in soil temperature above a plate (measured using a thermocouple) by soil depth and soil heat capacity, determined from soil type and measured soil water content (Campbell Scientific, 1998). Finally, results from the different sets of sensors are averaged to produce the average soil surface heat flux:

$$G = \frac{\left(\left(F_1 + C_{s1}\frac{\text{ä}T_1}{\text{ä}t}d\right) + \ldots + \left(F_x + C_{sx}\frac{\text{ä}T_x}{\text{ä}t}d\right)\right)}{x}$$

Where:
G = average soil surface heat flux [MJ m^{-2} s^{-1}]
F_X = soil heat flux, measured by sensor set x [MJ m^{-2} s^{-1}]
C_{SX} = soil heat capacity (the amount of energy required to increase the temperature of a unit volume of soil by one degree, related to the soil's mineral composition and water content), measured by sensor set x [MJ m^{-3} °C^{-1}]
T_X= soil temperature, measured by sensor set x [°C]
t = time [s]
d = soil depth [m]
x = number of sensor sets

A data logger controls the measurements, samples the sensors, processes incoming data, averages measurements over a period of time, calculates new parameters based upon measured ones, and saves the measured/calculated data to a storage medium. All electronics may be powered by a rechargeable battery connected to solar panels.

The BREB method requires accurate measurement of vapour pressure and air temperature at different levels above the surface. Also, measurement of soil heat flux is complex and cannot be easily obtained. Therefore, application of the above described method is mainly restricted to research stations (Allen *et al*., 2004).

The CO_2 /BREB system installed at the Tim research site not only measures the required micro-meteorological variables for BREB calculation but also wind speed, wind direction, precipitation, relative humidity and photosynthetically active radiation (PAR). An IRGA analyses air samples for concentration gradients both in water vapour and in carbon dioxide. Preliminary results indicate that net CO_2 fluxes are positive towards the surface so that rangelands in Uzbekistan may be important for carbon dioxide storage and may play a significant role in the global warming debate (Johnson *et al*., 1999).

7.6.3 Simulation with a soil water balance model

Simulation with a model can help estimate the influence of environmental parameters (especially climate/soil related) on the behaviour of a crop with the help of mathematical expressions and a minimum of field experiments. BUDGET is an example of a soil water balance model which tries to describe the processes involved in water extraction by plant roots and movement of water in the soil (Raes, 2002). By calculating the water content in a soil profile as affected by input and output of water during the simulation period, the program is suitable to assess crop water stress, to estimate yield response to water, and to design/evaluate irrigation strategies. In addition, the salt content of a soil profile is calculated making it possible to study the build up of salt in the root zone, for example under adverse irrigation conditions.

Since the soil water variation, calculated in a subroutine, depends on the actual soil water content, the order of execution of the different subroutines, which is predetermined by BUDGET, might theoretically have an influence on the final simulation result (Raes, 2002). Also, not all processes responsible for the actual water content in the soil are taken into account by the program; it considers the effect of drainage, infiltration and evapotranspiration but ignores the water transport due to capillary rise in case of a shallow ground water table, and while the effect of surface runoff on the amount of infiltration is taken into account, the interception of rain or irrigation water by the crop canopy is not explicitly described in the model (Raes *et al*., 2006).

Sensitivity analysis illustrated the robustness of BUDGET to yield simulation, even when no more than indicative values for crop and soil parameters are available. The program only requires a minimum of input data, which is readily available or can easily be collected (Raes *et al*., 2006). That makes the model generally applicable, not only in research station situations, but also under farmer conditions.

Since rainfall is the most important input of water in non-irrigated areas, it may not be surprising that BUDGET requires, preferentially, daily above 10-daily or monthly rainfall data in order to estimate the soil water balance correctly. Two different sets of rainfall data were available for the Karnab Chul region: one set with 20-minute data ranging from 1998 to 2002, electronically measured by the BREB station at the research site in Tim (referred to as 'the BREB data/dataset'), and one set with daily data ranging from 1998 to 2003, manually measured at the same location. Both datasets, but particularly the BREB rainfall data, contain large gaps of missing data, and the manually measured set differs significantly in distribution and amount of rainfall from the electronically measured set.

7.7 Dependable rainfall

Dependable rainfall is an estimate of the rainfall amount that can be expected for a specific probability of exceedance during a specific reference period. For example, the 20% 10-daily dependable rainfall is the amount of rainfall that will be reached and eventually exceeded in a decade with a probability of 20 %. The lower the prob-

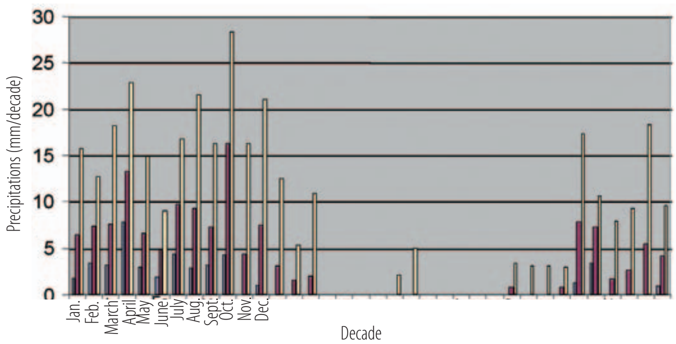

Figure 8. 10-daily dependable rainfall that can be expected in Tim village during a wet year (blue/light grey bars), a normal year, (red/dark grey bars), and a dry year (yellow/white bars).

ability, the higher the dependable rainfall, thus the 20%, 50% and 80% annual dependable rainfall is the rainfall amount that can be expected in a wet, normal and dry year respectively. As frequency analysis estimates of the probability of occurrence of future events are based on the analysis of events recorded in the past, the data series should be long enough to be valid.

Here, the 10-daily dependable rainfall that can be expected in a wet, normal and dry year was estimated for the Karnab Chul region. The values can be used as input for BUDGET, together with the previously mentioned average number of showers per 10 days, in order to design irrigation schedules for different type of years.

However, the results on dependable rainfall must be interpreted with care. In the first instance, because the interpolated dataset only covers ten years, where at least thirty years of data would be advisable for frequency analysis. Secondly, software needs five non-nil values as a minimum in order to perform its calculations. But since even the interpolated dataset is incomplete, when in a certain year and a certain decade the rainfall value for more than three days was unknown, the sum of rainfall was supposed to be invalid for that decade and wasn't considered in the frequency analysis. And because summer rain is scarce in the region, the required number of non-nil values was not available for all decades. In such cases, the 20%, 50% and 80% dependable rainfall was supposed to be zero for that decade.

7.8 Simulation of rangeland productivity under optimal management

The water balance model BUDGET was chosen as a tool to simulate *Artemisia* yield and grazing capacity of the Karnab Chul region in dry, normal and wet years. BUDGET (Raes, 2005) needs an input dataset, which consists of rainfall, crop and soil related data. Afterwards, the input data was analysed and corrected for errors, the model was calibrated and validated for the extreme climatological conditions experienced over the Uzbek steppe, and the expected yields under various conditions were determined by simulation.

The resulting seasonal relative yield (Ya/Ym) predictions show that only small variations between biomass production in a dry, normal and wet year can be expected. Also, maximum relative yield is never reached, not even in a wet year. The last two phenomena (illustrated by Table 3) might be explained by the fact that even in a wet year, no rainfall occurs during the critical summer months. Thus, extra precipitation during spring may increase the yield a little, but water stress in summer always keeps biomass production submaximal.

It must be noted that the preceding results and conclusions are just indicative – frequency analysis of rainfall data was only supported by ten years of data because validation for ET didn't prove that BUDGET had been calibrated correctly, and given that the estimated yield response factor (Ky) could not be checked to be valid. However, supposing that more reliable input information becomes available, and if the maximal yield under fully irrigated conditions (Ym) together with the required amount of (*Artemisia*) fodder per sheep and per year was

	wet year		normal year		dry year	
	rY [%]	rET [%]	rY [%]	rET [%]	rY [%]	rET [%]
Karnab Chul	78	35	76	28	74	24

Table 3. Seasonal relative yield (rY=Ya/Ym) predictions and their corresponding seasonal relative evapotranspiration (rET=ETa/ETc) values for wet, normal and dry conditions in the Karnab Chul region

known, the grazing capacity of the Karnab Chul region could be assessed.

All these activities were completed to develop a procedure to describe the ecological status of rangelands under different natural and anthropogenic pressures. On the basis of this work, it is planned to prepare an e-map of rangelands productivity. This map will help coordinate grazing pressure so that rangeland resources can be used more efficiently based on principals of ecosystem functioning.

Initial steps on the application of GIS, RS (remote sensing) and ecosystem modelling to characterise productivitypotential were carried out over the two last years. Specialized training on GIS and RS, using ESRI (Environmental System Research Institute) and ENVI (Remote Sensing software Institute) products, were conducted in the summer of 2006. There were twelve researchers who gained on-hand knowledge and training. ESRI (Germany) representative, Martin Kullmann, spent two months in Samarkand with this aim. During the training, researchers became acquainted with the theoretical principals and practical application aspects of GIS and RS. The best students were certified by the ESRI representative and are now considered resource persons for further projects. Several satellite images (Landsat, Ikonos, Resource) were processed and used to calculate environmental parameters. These indexes show a current status of vegetation cover. On the basis of these indicators or indexes it is planned to complete a map of seasonal biomass productivity, which can be used for managing optimal grazing strategy in the research area, and can be applied later it to similar areas.

Several other in-country training and visiting scientist programmes were conducted as well. Our partners from USA, Germany, and France did their best to organise these training sessions both in Samarkand and abroad.

8. Recommendations for sustainable dryland management

The serious problems raised by environmental management and regional sustainable development lie eventually in the hands of policy makers. Their action must be based on sound physical and socio-economic scientific expertise, which requires both a disciplinary and interdisciplinary approach within an integrated environmental framework, the so-called IEA 'Integrated Environmental Assessment'. In order to contribute to food security, poverty alleviation and environmental protection in arid regions and other dryland regions it is important to:

- Increase production, household income and welfare by in-depth processing of agricultural products and diversification of small-scale farms.
- Conserve or halt degradation of natural resources by involving local peoples throughout various training and participatory activities.
- Assess the current status of agro-ecosystems and the combined impact of technologies on ecological

changes as well as ensuring the efficiency with which resources are used for increasing human living standards at the levels of the farm, the collective farm, village and landscape.

- Site assessments should take into account a broad range of information that can help understand processes of change as well as the actors that participate in these changes. A variety of ethno-scientific methods could be employed including the reconstruction of landscape histories, and interviewing knowledgeable villagers.

The GIS and modeling methodologies are the only available ways to integrate vast amounts of available data on drylands (soil, vegetation, climate, population) with new approaches to provide managers and decision-makers at the local and regional scales an adequate tool to increase productivity and ensure the sustainability of drylands so as to satisfy the needs of the human population in the region. The results of this assessment will help scientists understand trends in terms of local biodiversity degradation, and will offer ideas for their better management and help identify particularly dynamic, resourceful and resilient components of the village.

8.1 Project achievements

1. The GIS and modeling methodologies are the only available way to integrate vast amounts of available data on drylands (soil, vegetation, climate, population) with new approaches to provide managers and decision-makers at the local and regional scales an adequate tool to increase productivity and ensure the sustainability of drylands so as to satisfy the needs of the human population in the region.
2. The results of this assessment will help scientists understand trends in local biodiversity management, but also will help identify particularly dynamic, resourceful, and resilient components of the village.
3. Assessment work on the current status of the natural resources was started towards the latter part of 2005.

Figure 9. Prof. D. Walling visiting from Exeter University.

A detailed electronic database on soil, climate, flora, fauna, and the socio-economics of the study area was prepared. Advanced techniques for doing these kinds of analyses are available, for instance, using ESRI and ENVI products. Both companies provided consultancy to use this product. Several layers of environmental information were integrated into the principal data frame. This framework consists of the following parts:
   - Climate.
   - Soil (agro-chemical, agro- physical, biological characteristics).
   - Biomass monitoring (mean monthly, palatable, unpalatable).
   - Land/use land cover change.
   - Land-use change and socio-economy.
   - Integration and syntheses.
4. Assessment of climate over time, in an historic and modern time perspective, has a very important value in terms of a comparison with the indicators of degradation. Using climatological data covering the period from 1948 to 2006 obtained from the Uzbek Meteorological Organization and several stations nearby, a database for climate was prepared. This long-term database includes several climatic parameters such as precipitation (quantity, interannual variability, mean monthly, seasonal distribution, numbers of days with snow, temperature); temperature (min, max, mean daily, monthly etc); wind (speed, direction); radiation

(net, photosynthetic active, duration of sunshine); relative humidity.

5. Primary environmental data represents a huge reuse value. It can be later be aggregated into distribution maps, provide a retrospective view of the status and distribution of natural resources and, after precise analysis, can be projected onto a larger area with various environmental conditions, and at different climate change and anthropogenic scenarios.

9. National seminars

1. Several national seminars were held. The first national seminar was dedicated to assembling a multidisciplinary assessment team, reviewing the literature, and choosing appropriate methodologies to characterize the proposed study area. The multidisciplinary team consisting of experts from leading organizations was set up, and the assessment methodology of agro-ecosystems was chosen. Verifiable indicators of sustainability were identified during this seminar. A variety of methods such as expert opinion, field monitoring, productivity changes, farm-level studies, GIS, and ecosystem modeling were chosen for this kind of participatory approach in which researchers necessarily play at least a facilitator role, but where the indicators are certainly meaningful to local people as well as to the analysts.

2. The latest national seminars were devoted to discussion of yearly work performed both in the field and at the laboratories. Several guest visitors were invited to attend the national seminars each year. They all are leading experts in their own area of research: Dr. Fee Busby and Dr. Douglas Johnson from Utah State University made a presentation on range improvement work based on their experience in the Western United States. Guest visitors from USA also spent one week at the research site and demonstrated modern techniques in the revegetation of degraded lands and biomass monitoring.

Prof. D. Walling from the University of Exeter, UK, described his modeling work on the assessment of erosion using 137Cs data from the Karnab Chul research site. Two students from Samarkand State University were identified as candidates for a MS sandwich programme on the application of the soil erosion model using the database compiled from the Karnab Chul area. Prof. D. Walling kindly agreed to be a co-promoter for this work.

Prof. Hans Schnyder from the Technical University of Munich gave a presentation on the distribution pattern of C_3 and C_4 plants due to climate change and desertification. He also spent time at the research site and gave mobile training on plant identification and characterization in field conditions both to farmers and project members. His presentation on ancient carpets, and the pollen they contain, as a source for environmental studies attracted a lot of interest from the participants.

3. The final national seminar took place in early September 2007. All project members as well as experts from cooperating organizations were invited to discuss all the obtained results. An article on the main ideas hammered out during this project for publication, in an issue of the scientific journal of the Samarkand State University, was discussed. Leading experts as well as young scientists had the opportunity to share their ideas with a large audience and therefore push the interesting findings forward.

List of participants attending the final seminar:

- M.G. Nasyrov – team leader, Samarkand State University.
- F.D. Kabulova, S.E. Fundukchiev, V.A. Onishenko, E.V. Fidirko, H. Narmuratov, A. Niyazov, M. Abdullaeva, D. Khodjaev, M. Muminov, Samarkand State University.
- B.K. Mardonov, T. Rajabov, F. Babajanov, D. Rakhimov, Samarkand Division, Academy of Sciences of Uzbekistan.
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Figure 10. Prof. Schnyder from Munich University of Technology (TUM), as a visiting guest.

- A. Hasanov, U. Baymuratov, B. Hasanov, Karnab Chul station.
- Representatives from NGOs: three participants (income-generation, tourism, wool processing).
- MSc and PhD students: 10 participants.

10. Research institution and team composition

10.1 Research institution

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11. Publications as a result of SUMAMAD

Ahmedov, A. 2007. *GIS and RS as a tool to describe vegetation cover in Karnab Chul area.* MS thesis. Supervisor: Prof. Muhtor G. Nasyrov, Samarkand State University, Faculty of Biology, Department of Plant Physiology and Microbiology.

Beliën, W. 2005. *Productivity of Artemisia rangeland in Uzbekistan* (Karnab Chul region of Uzbekistan), MS thesis. Supervisor: Prof. Dirk Raes, K.U. Leuven, Belgium, Departement Landbeheer en economie, Afdeling Bodem-en Waterbeheer and Prof. Muhtor G. Nasyrov, Samarkand State University, Uzbekistan, Faculty of Biology, Department of Plant Physiology and Microbiology.

Muminov, M. 2006. *Upscaling CO_2 and H_2O Fluxes from Tower to Landscape*. MSc thesis. Supervisor: Prof. Muhtor G. Nasyrov, Samarkand State University (Uzbekistan), Faculty of Biology, Department of Plant Physiology and Microbiology.

Nasyrov, M. G. 2007. The carbon sequestration potential of rangelands of Uzbekistan. In: *Proceedings of International conference: Role of Agro-ecosystems to Sequester Carbon and Mitigate Climate change*. Poitiers, France 16–19 July.

Nasyrov, M. G. 2007. Bowen Ratio Energy Balance System Approach to Monitor Net Primary Productivity in arid Environment of Uzbekistan. International Congress of Russian Society of Plant Physiologists, 19–23 June, Siktivkar, Russia. [In Russian]

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Acronyms

ACV	average conservation value

ADD	*Association de Développement Durable,* [Sustainable Development Association] – Tunisia

AJF	Agha Jari Formation

AM	aquifer management

ANPP	aboveground net primary production

APBB	*Association de Protection de la Biodiversité,* [Association for the Protection of Biodiversity] – Tunisia

ARG	artificial recharge of groundwater

ASNAPED	*Association de Sauvegarde de la Nature et de Protection de l'environnement de Douiret* [Association for the Safeguard and Protection of the Environment] – Tunisia

AWC	available water capacity

BAS	Baba Arab Station – Iran

BF	Bakhtyari Formation – Iran

BNPP	belowground net primary production

BR	Bowen Ratio

BREB	Bowen Ratio Energy Balance

CACV	cumulative average conservation value

CAREERI	Institute for Cold and Arid Regions Environmental & Engineering Research – China

CD	crown diameter

CRDA	*Commissariat régional de développement agricole* [Regional Department of the Ministry of Agriculture Regional Department of Agriculture] – Tunisia

CV	coefficient of variation

DBH	diameter at breast height

DEM	digital elevation model

DT	Tunisian dinars

EC	electrical conductivity

EIS	Environmental Information System

ENVI	Environment for Visualizing Images (remote sensing software)

ESRI	Environmental System Research Institute

ETP	evapotranspiration

EWR	Environmental Water Requirement

FAO	Food and Agriculture Organization of the United Nations

FC	field capacity

FCC	False Colour Composite

FIG	farmer interest group

FWS	floodwater spreading

GBP	Gareh Bygone Plain – Iran

GDP	Gross Domestic Product

GEF	Global Environmental Facilities

GIS	Geographic Information System

GPS	Global Positioning Satellite System

GTZ	*Gesellschaft für technische Zusammenarbeit* [German Agency for Technical Cooperation]

HRB	Heihe River Basin – China

HRBAB	Heihe River Basin Administrative Bureau

HYFA	Hydrological Frequency Analysis [software]

ICARDA	International Centre for Agricultural Research in the Dry Areas

IO	*Institut de l'Olivier* [Research Institute for the Improvement and Productivity of Olives] – Tunisia

IRA	*Institut des régions arides* [Institute of Arid Regions] – Tunisia
IRGA	infrared gas analyser
JZ	*Association des Jeunes de Zammour* [Zammour Youth Association] – Tunisia
KS	Kowsar Station – Iran
MAP	mean annual precipitation
MEA	Millennium Ecosystem Assessment
MEDD	*Ministère de l'Environnement et du Dével-oppement Durable* [Ministry of Environment and Sustainable Development] – Tunisia
mha	million hectares
MPHRB	Master Plan of the Heihe River Basin – China
NPK	Nitrogen, Phosphorous, Potassium
NPP	Net Primary Production
OBR	Omayed Biosphere Reserve
OEP	*l'Office de l'Élevage et des Pâturages de Tunisie* [Office of Livestock Breeding and Pastures]
OTD	*Office des Terres Domaniales* [Office of Domanial Land] – Tunisia
PAR	photosynthetically active radiation
PCRWR	Pakistan Council of Research in Water Resources
PGIS	Participatory Geographic Information System
PLAR	Participatory Learning and Action Research
RI	recurrence interval
RS	remote sensing
RSCN	Royal Society for the Conservation of Nature – Jordan
RUE	rainfall use efficiency
RUSLE	Revised Universal Soil Loss Equation
SAR	sodium adsorption ratio
SEPA	State Environment Protection Administra-tion – China
TDS	total disolved solids
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNU-INWEH	United Nations University – International Network on Water, Environment and Health
USLE	Universal Soil Loss Equation
WAHIA	Water Harvesting Impact Assessment [European Union project]
WHC	water holding capacity
WHT	water harvesting techniques
WUA	Water Users Associations
WUE	water use efficiency

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SUMAMAD

This publication synthesises the results of the Sustainable Management of Marginal Drylands project funded by the Flemish Government of Belgium. Scientists from nine countries: Belgium, China (HRB, HS), Egypt (OBR), the Islamic Republic of Iran (GBP), Jordan (DBR), Pakistan (D/LSBR), Syria (KVIRS), Tunisia (ZKW), and Uzbekistan (KC) studied dryland ecosystems from a research, environmental conservation and sustainable development perspective. Their objective was to elaborate wise dryland management practises by involving local communities while satisfying their needs for sustainable livelihoods. Study sites included field research stations and biosphere reserves, which also served as testing grounds for alternative income opportunities among dryland communities based on their perceived needs and priorities. It is hoped that the knowledge gleaned from the individual project sites will also benefit dryland regions in other parts of the world.