G. Ali Heshmati · Victor R. Squires
Editors

Combating Desertification in Asia, Africa and the Middle East

Proven practices

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Editor's Preface

The stimulus for producing this collection of important and detailed case studies on combating desertification arose from our involvement in the International Training Course on Desert Control Science and Technology sponsored by the Ministry of Commerce, which has been held in Wu Wei, Gansu, for many years under the auspices of the Gansu Desert Control Research Institute (GDCRI). The training course drew together participants from many countries, and these people were able to share their experiences as well as learn new techniques and approaches that have potential to be applied in their respective homelands.

But as we pondered the problems faced by many countries in their efforts to arrest and reverse accelerated land degradation and loss of productivity and its deleterious impacts on people and their livelihoods, we came to realize that most publications about desertification focus on the reasons for it, its proximate and underlying causes and on debates about whether humans cause desertification or whether it is all because of climate change. These matters are important discussion points, but there is still the question of 'how *do* we go about combating desertification?'

Emphasis on the "why?" has its place, but there is an urgent need to share information about successful and proven approaches and field techniques that could be applied elsewhere in the world.

The International Training Course on Desert Control Science and Technology has been conducted by the Gansu Desert Control Research Institute (GDCRI) and sponsored by the Ministry of Commerce for 13 years now. They bring together researchers, academics, land administrators and policy makers from a wide range of African and Asian countries. The sharing of experiences, the formal lectures and study tours all help to strengthen the appreciation of the technical advances wrought in China in the field of desertification control. The Training course also provides an opportunity to consider the interplay of social, economic and cultural aspects and the importance of creating an enabling environment (legislative and regulatory) in which the integrated approach can succeed. Similarly, the need to forge a link between science and community action becomes clear.

The world's drylands occupy a vast region and are home to more than 2.5 billion people. Many of the world's regions are adversely affected by desertification. Here the full interplay of human-induced environmental change and the often harsh and unpredictable climate is being experienced. Dryland regions have such a delicate balance between the number of people and the capacity to have food security. Many regions in Africa and Asia have undergone upheaval (social and economic) in the past 50–70 years.

The fight against land degradation in terrestrial ecosystems forms one of the most complex challenges with regard to the various global environmental problems. It is most intensively linked to human life quality and to current living conditions in the poorer countries of the drier biomes on earth. The concept of the combat of desertification, as rooted in the charter of the United Nations Convention to combat Desertification and Drought (UNCCD), can also be transferred to a wider sustainability agenda for the more humid ecosystems where accelerated land degradation, loss of biodiversity and vulnerability to climate change are emerging issues of global significance.

Serious land degradation is a problem that many countries face. The economic costs are significant but the human tragedy of crops and animals destroyed, and lives lost bring home the true nature and extent of the problem. Add to this the impact on biodiversity and the impact on global climate change as the albedo changes.

China is one of many countries around the globe facing the serious problem of desertification. The Chinese Government attaches great importance to combating desertification and to the improvement of ecosystems and the environment, and have incorporated, as a basic state policy, desertification combating, ecology improvement and environmental protection into the National Economic and Social Development Plan.

China has led a long struggle against land degradation and desertification. As early as the 1950s, the Government of China organized scientific surveys and studies on affected lands and has given priority to combating desertification in seriously impacted regions. Since the 1970s, China has initiated and implemented successively such major ecology restoration projects such as the Three North Regions Shelter Belt Development Project, the Coastal Protection Shelter Belt Project, the National Action Program to Combat Desertification, the Plain Farmland Protective Networks project and the Green Belt Establishment Project along the Middle and Upper stream of the Yellow River. All these projects have accumulated successful experiences and scored remarkable achievements, with many convincing models emerging. Since the 1990s, the National Action Program to Combat Desertification (NAP) and the Three North Region Shelter Belt Development Project have brought more than 16 million ha of farmland and 10 million ha of rangeland under effective protection.

In this volume, we draw together case studies from such diverse countries as Sri Lanka, an island nation in south Asia, Uzbekistan and Mongolia from Central Asia, China, Iran, Kenya, Lesotho and The Philippines, with its extensive archipelago, in SE Asia. This diversity, in terms of climate geography, stage of economic development and systems of governance, makes for contrasts in the approach adopted and the outcomes recorded.

We also weigh into the debate the differences between 'fighting or taming the desert' and the urgent task of arresting and reversing desertification – a totally different agenda. Spectacular and costly measures directed at pushing back the desert or 'making the desert bloom' are a distraction from the real task of implementing more sustainable land use practices and changing the enabling environment that will allow better land stewardship to take root and prosper.

The lessons to be learned from experiences in several contrasting geographic regions of the world presented here should be especially valuable in framing the action plans of the various countries in the dryland regions of Africa, Asia and the Middle East. The opportunity presented by the compilation of this report is therefore to be greatly welcomed and timely.

Many agencies in China and elsewhere have a special interest in the problems (and solutions) outlined in this report. Because many of the problems involved are transnational in their nature and geographic spread, it is important that international cooperation is promoted to effect solutions, to coordinate research and share information.

We believe that this book will prove to be of value to land managers, researchers, aid agency personnel and UN system bureaucrats – all of whom are struggling to arrest and reverse the scourge of land degradation.

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Contents

Part I Deserts and Desertification in China

1 **Introduction to Deserts and Desertified Regions in China** 3
G. Ali Heshmati and Victor R. Squires

2 **Controlling Sand Movement Through Mechanical Measures: China's Experience** 21
G. Ali Heshmati

3 **Successful Biological Methods for Combating Desertification at Degraded Areas of China** 49
G. Ali Heshmati

Part II Deserts and Desertification in Three North African Countries

4 **Libya: Reversal of Land Degradation and Desertification Through Better Land Management** 75
Ali Mansour Saad, Noresah Mohd Shariff, and Sanjay Gariola

5 **Desertification and Its Control in Morocco** 91
Y. Hammouzaki

6 **Egypt: Land Degradation Issues with Special Reference to the Impact of Climate Change** 113
Kh. Darwish, M. Safaa, A. Momou, and S.A. Saleh

Part III Deserts and Desertification in Other African Countries

7 **Combating Desertification in Kenya** 139
P.M. Nguru and D.K. Rono

8 **Lesotho: Desertification Control Program** 153
S. Moshoeshoe and M. Sekantsi

9 **Desert Environments of Republic of Chad** 169
Hakim Djibril

10 **Desertification Control in Niger: The Medium Term Action Plan 2006–2011** 191
Ibrahim Abdou

Part IV Desertification in Selected Asian Countries

11 **Mongolia: Country Features, the Main Causes of Desertification and Remediation Efforts** 217
O. Dorj, M. Enkhbold, S. Lkhamyanjin, Kh. Mijiddorj, A. Nosmoo, M. Puntsagnamil, and U. Sainjargal

12 **Arid Land Development and Combating Desertification in Pakistan** 231
M. Shahbaz, Muhammad Khalid Rafiq, and Taj Naseeb Khan

13 **Uzbekistan: Rehabilitation of Desert Rangelands Affected by Salinity, to Improve Food Security, Combat Desertification and Maintain the Natural Resource Base** 249
K.N. Toderich, E.V. Shuyskaya, T.F. Rajabov, Shoaib Ismail, M. Shaumarov, Kawabata Yoshiko, and E.V. Li

14 **Review of Efforts to Combat Desertification and Arrest and Reverse Land Degradation in Myanmar** 279
N.N.O. Weine

15 **The Philippines Action Plan to Combat Desertification, Land Degradation, Drought and Poverty** 303
G.M. Castro Jr.

16 **Managing Arid Areas and Sand Dunes in Sri Lanka** 323
R.P.M. Weerasinghe

Part V Combating Desertification in the Middle East

17 **Indigenous Plant Species from the Drylands of Iran, Distribution and Potential for Habitat Maintenance and Repair** 355
G. Ali Heshmati

18 **Soil and Water Conservation for Desertification Control in Iran** 377
Ali Najafi Nejad

19 **Land Degradation in the Sultanate of Oman: Reasons and Intervention Measures** 401
H. Al-Hashmi

Part VI Desertification Control: Problems and Prospects

20 Desert Development: How Does It Relate to Anti Desertification Measures? 427
Victor R. Squires

21 Replication and Scaling Up: Where to from Here? 445
Victor R. Squires

Appendix 461

Glossary 467

Index 471

Contributors

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Acronyms and Abbreviations

ADB	Asian Development Bank
ACIAR	Australian Center for International Agricultural Research
ARIS	Agricultural Resources Information System (ARIS)
ASALS	Arid and Semi Arid Lands (In Kenya)
ASLR	Accelerated Sea Level rise
AU	African Union
BSWM	Bureau of Soil and Water Management
CAP	Common Agricultural Policy
CBD	UN Convention on Biodiversity
CBO	Community-based organizations
CCCD	(see also UNCCD)
CDM	Clean Development Mechanism
CITES	Convention on International Trade in Endangered Species
DOA	Department of Agriculture
DSS	Dust and Sand Storms
EEAA	Egyptian Environmental Affairs Agency
ESCAP	Economic and Social Commission for Asia and Pacific
ESCWA	Economic and Social Commission for West Asia
FAO	UN Food and Agriculture Organization
FATA	Federally Administered Tribal Areas in NW Pakistan
FCCC	UN Framework Convention on Climate Change
GEF	Global Environmental Facility
GIS	Geographic Information System
GM	Global Mechanism
GNP	Gross National Product
GoK	Government of Kenya
GoP	Government of Pakistan
GoSL	Government of Sri Lanka
ICDD	International Commission on Dryland Development
ICM	Integrated Catchment Management
IEMP	Integrated Ecosystem Management Project

IFAD	International Fund for Agricultural Development
IPCC	Inter-governmental Panel on Climate Change
ITZC	Inter-Tropical Convergence Zone
JICA	Japan International Cooperation Agency
LARIS	Land Resources Information System (LARIS)
LHHWP	Lesotho Highlands Water Project
LUPPD	Land Use Policy Planning Division (Sri Lanka)
LUPRD	Land Use Planning and Rural Development
MASL	Mahaweli Authority of Sri Lanka
MTAP	In Niger, Medium Term Action Plan
MYDP	Multi Year Development Program
MoFE	Ministry of Forestry and Environment
MoFLR	Ministry of Forestry and Land Resources
NAP	National Action Plan
NCSA	(NCS) National Conservation Strategy
NEAP	Nature and environment Action Plan
NGO	Non Government Organization
NPACD	National Plan of Action to combat Desertification (Oman)
NPP	Net Primary Productivity
NREA	New and Renewable Energy Authority (Egypt)
NRMC	Natural Resources Management Center (Sri Lanka)
NUL	National University Lesotho
NWFP	In Pakistan, North West Frontier Province
ODNR	National Office Development of Natural Resources
MDG	Millennium Development Goals
SIS	Soil Information System
NDVI	Normalized Difference Vegetation Index
NCCD	National Committee for Combating Desertification (Mongolia)
MTAP	Medium Term Action Plan (Niger)
ODNR	National Office of Rural Development (Office National de Développement Rural) in Chad
PARC	Pakistan Agricultural Research Plan
NCEA	National Commission for Environmental Affairs (Myanmar)
NCC	National Climate Committee (Mongolia)
OISCA-International	Organization for Industrial, Spiritual and Cultural Advancement
JIFPRO	Japan International Forestry Promotion and Cooperation Agency
KOICA	Korean International Cooperation Agency
NFP	National Forest Policy (Myanmar)
SFM	Sustainable Forest Management
ICIMOD	The International Center for Integrated Mountain Development
IEMP	Integrated Environmental Management Program

PACD	Presidential Assistant on Community Development (The Philippines)
PAN/LCD	National Action Plan to Combat Desertification and Land Degradation (Chad)
PCAARD	Philippines Council for Agriculture, Forestry and Natural Resources
PDF-B	Project Development File Part B for GEF submissions
PPLCD	General Plan to combat desertification and land degradation (Chad)
SALT	Sloping Agricultural Land Technology
SLMP	Sustainable Land Management Planning
SLR	Sea Level Rise
SRD	Strategy for Rural Development (Niger)
SWC	Soil and Water Conservation
UNCED	United Nations Conference on Environment and Development
UNFCCC	See FCCC
UHCF	Unirrigated Highland Crop Farming Sri Lanka
UNSO	United Nations Sudano-Sahelian Office
WB	World Bank

List of Boxes

Box 1.1 Examples of International Collaborative Efforts to Combat Desertification (Source: Wang Jihe (2006, personal communication)) 16

Box 2.1 The Miracle of the Takliman Desert Highway 44
Box 2.2 The Shapotou Experimental Station, Ningxia, China 45

Box 6.1 Renewable Energy Wind Power 129
Box 6.2 Role of the Desert Research Center Arab Republic of Egypt Ministry of Agriculture and Land Reclamation 130

Box 7.1 Actions Taken at National and Local Level That Lead to Situation Betterment 150

Box 9.1 Wind Erosion Control in Bokoro 185
Box 9.2 Summary of Ennedi Project in Northern Chad 186
Box 9.3 Great Green Wall to Stop Sahel Desertification 187
Box 9.4 Reforestation Using *Acacia albida* 188

Box 11.1 GL-CRSP GOBI Forage Project: A Success Story 227

Box 15.1 Use of SALT in Practice – Step by Step 315

Box 16.1 Government Agencies Involved in Dealing with Land Related Issues in Sri Lanka 330
Box 16.2 Community Action Program to Reduce Land Degradation and Conserve Biodiversity in Maguru River Basin by Organization for Aquatic Resources Management – GEF Small Grants project 345

Box 17.1 Carbon Sequestration in the Desertified Dryland 372

Box 18.1 SuccessfulControl of Dust in the Meighan Desert, Markazi Province 387
Box 18.2 Pilot Project of Flood Spreading System 393
Box 18.3 Iran as Host to the UNCCD TPN3 397

Box 20.1 Desert Development Has Been a Strongly Supported Activity as Evidenced by the Number of International Conferences 429
Box 21.1 Eight Steps to Scaling Up 450
Box 21.2 The Many Facets of Success in Scaling Up 458

List of Figures

Fig. 1.1 There are several major climate zones with a high proportion of cold arid regions such as in the Qinghai-Tibet Plateau 7
Fig. 1.2 China has a large area of true desert (hyper arid and other areas of arid land) as well as extensive areas of sandy land on dry sub humid areas (Wu et al. 2007) 8
Fig. 1.3 Yardangs are a type of desert landscape that is shaped by wind and water. This set is from the Qaidam (Chadamupendi) Desert (Photo V. Squires) 9
Fig. 1.4 Riparian areas like this one on the lower reaches of the ShiYang river in the Hexi corridor of China have died as a result of over enthusiastic water conservation projects that prevented annual flooding after the spring snow melt and the cessation of ground water recharge 11
Fig. 1.5 Sand encroachment and accelerated desertification is forcing villagers to abandon their homes and migrate to other regions (Photos Victor Squires) 13

Fig. 2.1 Relationship between mechanical and biological measures 23
Fig. 2.2 Type of mechanical measure and its function 24
Fig. 2.3 The cross section of covering sand dune with earth 25
Fig. 2.4 Covering sand dunes with straw or branches 26
Fig. 2.5 The effect of ventilation sand barrier on sand-driving wind 29
Fig. 2.6 The effect of dense structural and windproof sand barriers on sand-driving wind 30
Fig. 2.7 The indication of the prevailing wind (**a**) is the initial condition after stabilizing the dune with standing sand barriers (**b**) is the location of plantings of trees and shrubs between the dunes and (**c**) the reduced size of the dune at some future time 31

Fig. 2.8 The run of sand barrier on the windward slope of dunes 32
Fig. 2.9 The patterns of some sand barriers 33
Fig. 2.10 The section of linear-shaped sand barrier 33
Fig. 2.11 The disposing patterns of sand barrier of the windward slopes of crescent dunes 34
Fig. 2.12 The disposing patterns of sand barriers on the semi-lunar dune chains 34
Fig. 2.13 The disposing patterns at the head of longitudinal dunes 35
Fig. 2.14 The disposing patterns of sand barrier on the complicated irregular sand dune 36
Fig. 2.15 The relationship between the height and the row spacing of the sand barrier 37
Fig. 2.16 The relationship between the slope of sand and the row spacing of sand barrier 37
Fig. 2.17 The relationship of the stable surface of sand dune and the concave part around the sand barriers 38
Fig. 2.18 The installing techniques of high standing sand barrier 40
Fig. 2.19 The installer's method of soft spread sand barriers 41
Fig. 2.20 Installation of materials in furrows 42
Fig. 2.21 The section of clay sand barrier. Major barriers are placed 2–4 m apart with a base of 15–25 cm in the lower slopes and 45–75 cm in the upper parts 42
Fig. 2.22 A view of part of the Shapotou Desert Research Station showing the system of checkerboards made with straw to increase surface roughness and reduce sand movement 46

Fig. 3.1 "The Great Green Wall" extends for hundreds of km in northern China to reduce the impact of dust and sandstorms that originate in Mongolia and Inner Mongolia 51
Fig. 3.2 Planting trees in the swales where soil water relations are better is a good way to flatten dunes over a period of several years as sand is transported downwind 57
Fig. 3.3 Shrubs that have a high resistance to wind erosion are planted on the front or middle part of the windward slopes of dunes and trees such as *Populus* can be planted on the downwind side 58
Fig. 3.4 An integrated approach to sand fixation in an artificial oasis threatened by encroaching sand dunes 61
Fig. 3.5 Comprehensive Shelter system in Gaotai county, Gansu 61
Fig. 3.6 Comprehensive system for sand control near Aydingkol Lake, Turpan county Xinjiang 62
Fig. 3.7 Flow chart for Shelter forest system to protect the artificial oases 63

Fig. 3.8 "Blocking shifting sand dunes at front and dragging at back" a schema for successful application in the Wushenqi area of the Mu Us sandy land in Inner Mongolia 63
Fig. 3.9 Sand fixation and afforestation on shifting sand in Zhanggutai, Horqin sandy land, Laoning, NE China 64
Fig. 3.10 Structure of a comprehensive protection system developed in the Shapotou section of Baotou-Lanzhou railway line 66
Fig. 3.11 Structure of sandbreaking forest in the Junkeng-Erdaogou section of the Lanzhou-Xinjiang railway 66
Fig. 3.12 Structure of the shelter belts in Ganqika section of the Dalushan-Zhongjiatun railway line, Inner Mongolia 67
Fig. 3.13 Structure and placement of wind-leading panels for highway protection 68
Fig. 3.14 Comprehensive Shelter system on two sides of a highway 68
Fig. 3.15 Mechanical barriers made of clay have proved to be successful in some areas. Clay 'tablets' of various sizes are used in mixtures (as shown) 69

Fig. 4.1 Map showing Libya and its neighbors and its geographic location in Africa 77
Fig. 4.2 Large-scale center pivot irrigation schemes are a feature of Libya's agriculture 78
Fig. 4.3 Irrigation depends on exploitation of large aquifers that underlie much of Libya 79
Fig. 4.4 Rehabilitation of degraded rangelands can involve planting fodder species that provide an intake of green material and also protect the soil surface. The photo shows a plantation in an 100 mm zone in Libya (Photo B.E. Norton) 83
Fig. 4.5 Plantations of *Atriplex* have been used with success. The green leaves are rich in protein and provide a useful supplement in late autumn or in drought times, if an energy source such as straw is available (Photo B.E. Norton) 84
Fig. 4.6 Furrowing to catch water and allow germination of wind blown seeds has been tested in Libya. Creation of surface roughness reduces run off and reduces wind velocity at or near the soil surface (Photo B.E. Norton) 85

Fig. 5.1 Map of Morocco showing its location and its neighbors.......... 93
Fig. 5.2 Average monthly rainfall and temperature of Fez (lat. 34° N and long. 5° W) 95
Fig. 5.3 Rainfall map showing that rainfall is low (100 mm p.a.) in most inland of Morocco 96

Fig. 5.4 Collection of seeds from rangeland plants, including trees and shrubs in Eastern Morocco 106
Fig. 5.5 Planting of long lived drought-resistant hardy perennials into rangeland can provide a valuable protein supplement during the dry season and a drought reserve. *Atriplex* spp. perform well (Photo B.E. Norton) 108
Fig. 5.6 A photograph of *Atriplex* in an alley cropping system with barley as the cereal crop (Photo B.E. Norton) 110

Fig. 6.1 Agro-ecological zones in Egypt 116
Fig. 6.2 Land use map of Egypt 117
Fig. 6.3 Satellite view of Nile Delta and part of the Mediterranean coast 118

Fig. 7.1 Kenya map showing Arid and Semi-Arid Lands (ASALS)....... 142
Fig. 7.2 Extensive rangelands are used by traditional pastoralists. Much of the better land has been put into national parks. Large areas have become degraded outside of the reserves 143
Fig. 7.3 Photo sequence from (**a**) 2004 to (**d**) 2007 of a typical site where controlled access has resulted in vegetation recovery . 147

Fig. 8.1 Mountains occupy a large part of Lesotho........................ 154
Fig. 8.2 Map of Lesotho, a land locked mountainous country in southern Africa.. 155
Fig. 8.3 Severe gullying in arable terraces in Lesotho 157
Fig. 8.4 Land use Map. The areas shown in green are the protected areas. Grazing land occupies the biggest area 158
Fig. 8.5 Grass cover in the mountains of Lesotho 159
Fig. 8.6 Indigenous trees of Lesotho (*Leucosidia sericea*)................ 159
Fig. 8.7 Showing gender balance in implementation of land rehabilitation activities 161
Fig. 8.8 A watershed is all the land that water flows across or through on its way to a specific tributary stream, or river 161
Fig. 8.9 Watersheds have boundaries and an outlet (mouth). They represent a useful management unit 162
Fig. 8.10 A basic gabion before filling with stones 163
Fig. 8.11 Section through a gabion dyke (stone filled baskets) used to protect stream banks and prevent erosion 163
Fig. 8.12 Cross section of gully plug showing details of construction...... 164
Fig. 8.13 Shows mechanical measures (Diversion furrow, stone lines and silt-traps respectively)................................. 165
Fig. 8.14 Public participation in afforestation in Lesotho 165

Fig. 8.15 Concrete tank to protect a spring. This project provided jobs and taught skills 166

Fig. 9.1 Map of Chad showing its location as a land-locked country located on the fringe of the Sahara desert 171
Fig. 9.2 Local livestock owners of livestock practice transhumance to chase the seasonal availability of forage and water 178

Fig. 10.1 Map of Niger Republic and it neighboring countries. The country is bordered to the north by Algeria and Libya, to the west by Mali and Burkina Faso, to the east by Chad and to the south by Benin and Nigeria 193
Fig. 10.2 Massifs of Air (Ing. foresters going to the steering committee meeting for Sustainable Co-management of the Natural Resources of the Air-Tenere Complex: Iferuan June 2012) 194
Fig. 10.3 Niger is a Sahelian country faced with many problems of desertification including loss of precious topsoil that threaten food security 197
Fig. 10.4 (**a**) and (**b**) Pressure on marginal lands for conversion to millet farms leads to rapid land degradation 199
Fig. 10.5 Water erosion in a millet farm 199
Fig. 10.6 Mechanical restoration of degraded land by women at Iferuan community, June 2012 202
Fig. 10.7 Moving sand dune (Maine-Soroa) Sep. 2012 (Compare Fig. 10.11 to see the value of the sand fixation work) 202
Fig. 10.8 Bush burning for agricultural purpose (create more arable land) 206
Fig. 10.9 Forest Rangers assessing the number of trees cut down to make way for cropping 207
Fig. 10.10 Members of the steering committee of Sustainable Co-management of the Natural Resources of the Air-Tenere Complex (C0GERAT in French) visiting a private site of outreach bridging (May 2012) 208
Fig. 10.11 Sand dune fixation at Maine Soroa Sep. 2012 209
Fig. 10.12 Women harvesting *Cassia tora* leaf (it is delicious food). This species has been reintroduced in 2008 in land restored within the UNEP IEMP project (Dogueraoua pilot site of IEMP October 2010) 209

Fig. 11.1 Geographic location of Mongolia and the location of population centers, It is the 18th largest country in the world, 5th largest in Asia 219

Fig. 11.2 The southern regions of Mongolia are desert whilst in the north and north-west there are uplands with forest cover 219
Fig. 11.3 Livestock production zones based on description by Suttie (2005) 221
Fig. 11.4 Natural zones of Mongolia showing principal vegetation types 223
Fig. 11.5 Trends in NDVI in five different zones of Mongolia from 1982 to 2006 223
Fig. 11.6 Over grazing is serious and often exceeds 150 % of the assessed carrying capacity 224

Fig. 12.1 Map of Pakistan showing distribution of rainfall. The darker areas receive higher rainfall 233
Fig. 12.2 Sprinkler irrigation for fodder production 245
Fig. 12.3 Shelterbelt technology to combat sandune shifting in Thal Desert 245
Fig. 12.4 Dry afforestation technology in Thal 246
Fig. 12.5 *Eucalyptus* wind break in desert 246
Fig. 12.6 Improved community rangeland in Balochistan 247
Fig. 12.7 Jatropha plantation on marginal lands for biofuel production 247

Fig. 13.1 Bordering Turkmenistan to the southwest, Kazakhstan to the north, and Tajikistan and Kyrgyzstan to the south and east, Uzbekistan is not only one of the larger Central Asian states but also the only Central Asian state to border all of the other four former Soviet Republics. Uzbekistan also shares a short border with Afghanistan to the south 252
Fig. 13.2 (**a**, **b**) Topographical landscape map of target research area in Kyzylkum desert (Karakata saline depression) The *dot in the square* in the large scale map (*right*) indicates the location in relation to the whole region. The salinity gradient on micro relief level includes the area between two artesian thermal springs (shown as *triangles*). The plant community and soil was studied along this gradient (Source: Toderich et al. 2008) 255
Fig. 13.3 Location of the study area in Karnabchul, Uzbekistan (**a**), digital elevation model (*DEM*) (**b**), schematic illustration of the measurement transects laid out perpendicular to the well (**c**), and village (**d**). DEM was obtained from Earth Remote Sensing Data Analysis Center (ERSDAC 2009; Rajabov 2011) 255
Fig. 13.4 Interrelation of typical fodder (*Artemisia diffusa*) and unpalatable species (*Peganum harmala*) along a grazing gradient from a fixed watering point in Karnabchul 258

Fig. 13.5 Dynamics of below- and above-ground biomass of ephemeroids as a response to different grazing intensities 259
Fig. 13.6 Mapping of dominating (edificators) plant C4 species on the territories of Kyzylkum desert along a gradient of salinity (1–4 soils of low salinity; 5–8 medium salinity; 9–12 high salinity) 263
Fig. 13.7 Ratio of species with C_3 and C_4 types of photosynthesis in different plant associations (**a** – xerophytes, **b** – xerohalophytes, **c** – haloxerophytes) during vegetation season 265
Fig. 13.8 Ratio of perennials and annuals among desert rangelands plant associations along salinity gradient. (**a**) is displayed according to location in landscape and (**b**) is displayed according to photosynthetic pathway (C_3 or C_4) 266
Fig. 13.9 Leaf carbon isotope ratio of C_3 (*T. hispida*) and C_4 (*H. aphyllum*) species along salinity gradient 267
Fig. 13.10 Ion average concentrations detected in the aboveground biomass of salt tolerant rangelands species at the flowering stage 268
Fig. 13.11 (**a**) Natural pastures at Kyzylkesek site highly affected by salinity (before improvement); (**b**) rehabilitation of saline prone lands by using *Atriplex nitens* (monotypic cultivated halophytic pasture after improvement) ... 269

Fig. 14.1 Map of Myanmar, the 5th largest country in Asia showing the location and extent of the Dry Zone in central Myanmar (*inset*) 283
Fig. 14.2 Severe gullying and soil loss can follow deforestation and inappropriate cultivation methods 290
Fig. 14.3 Severe gullying may require structural works to reduce flow and trap sediment.................................... 291
Fig. 14.4 Structural gully control works are an effective means for control of sediment movement 291
Fig. 14.5 Earthworks such as these can reduce runoff and soil loss and retain moisture in situ 292

Fig. 15.1 Location map of the Philippines within SE Asia 305
Fig. 15.2 The Philippines is an island nation................................ 306
Fig. 15.3 Soil erosion takes many different forms as this map shows. Severe erosion (shown in *red*) is more common in the south.. 310

Fig. 16.1 Sri Lanka is a tropical country with a land area of 65,610 km^2 .. 325
Fig. 16.2 Rainfall varies from very high >5,000 mm annually to low <1,250 mm in the so-called dry zone 326

Fig. 16.3 There are extensive areas, especially in the Horton Plains area that are covered with patana grass (*Chrysopogon zeylandicus*) ... 329
Fig. 16.4 Soil erosion control works like these are being used to (**a**) control water flow and (**b**) create terraces ... 334
Fig. 16.5 Erosion damages crops and makes areas of land less productive. Gullying in a cropped field can expose of bare rocks ... 336
Fig. 16.6 Soil erosion hazard map of central region of Sri Lanka. The severity is expressed as low (*pale gray*), moderate, high, very high and severe (*red*) ... 337
Fig. 16.7 Tea plantations are important but their establishment has contributed to deforestation ... 339
Fig. 16.8 Coconut plantations can provide soil protection ... 339
Fig. 16.9 Rubber plantations occupy uplands. They have replaced native forest ... 340
Fig. 16.10 *Casuarina equisetifolia* plantations in Hambanthota District coast line ... 343
Fig. 16.11 Sand dune stabilization by erection of semi-permeable (slatted) fence to change wind flow patterns and reshape dunes ... 344
Fig. 16.12 Layout of slatted fences to stabilize sand plains Fences are about 6–80 cm high ... 344
Fig. 16.13 Stone walls were built by the local community to combat erosion ... 346
Fig. 16.14 Community consultation is an important part of the development of land use plans ... 347

Fig. 17.1 Geographical location and topographic features of Iran. Elburz and Alborz are alternative spellings for the principal east-west mountain chain ... 357
Fig. 17.2 Natural vegetation and elevation level on different aspects of Alborz mountain ... 359
Fig. 17.3 Distribution of four ecological zones of Iran ... 360
Fig. 17.4 The Caspian ecoregion has a great diversity of halophytes ... 365
Fig. 17.5 Tree and shrub seedlings are produced in irrigated nurseries that are protected by windbreaks and have water available for supplementary irrigation ... 368
Fig. 17.6 Prevention of the wind erosion can be achieved by covering the surface with obstacles that reduce wind velocity at the surface ... 368
Fig. 17.7 Bulldozer towing oil/seed spraying equipment into position ... 369
Fig. 17.8 Dunes can be stabilized by a combination of biological methods involving planting shrubs and grasses inside small areas protected by pallisades ... 369

Fig. 17.9 Reclamation of desert lands with resistant species such as *Atriplex* spp. and *Haloxylon* spp. 370
Fig. 17.10 Harsh desert environments like this pose a real challenge to those who wish to re-vegetate 371
Fig. 17.11 Millions of plants are produced each year. Nurseries like this one are the backbone of this effort to reproduce locally adapted plants for transplanting (Photo Behrouz Malekpour) 372

Fig. 18.1 Iran has a large arid zone. It borders on the Caspian Sea, the Persian Gulf and several Central Asian Countries to the east 380
Fig. 18.2 Overgrazing leads to loss of vegetation and accelerated run off and soil loss (Photo by author) 381
Fig. 18.3 Severe gully erosion in loess area 382
Fig. 18.4 Gully development is a kind of land degradation in Atrak river basin 382
Fig. 18.5 There are large tracts of denuded sandy land. Overgrazing has led to formation of unstable dunes that threaten roads, railways and settlements 389
Fig. 18.6 The psammophytic plant *Nitraria schoberi* can be used to stabilize moving sand 389
Fig. 18.7 Small dams allow water harvesting and assist in flood mitigation in an upland catchment of Atrak river 390
Fig. 18.8 Biological measures involving planting of trees and shrubs for rehabilitation of degraded lands 391
Fig. 18.9 Participatory approaches are a way to involve the local land users in project planning, implementation and monitoring 392
Fig. 18.10 Community participation in tree planting and other revegetation efforts is a way to ensure the sustainability of projects 392
Fig. 18.11 Flood water spreading and utilization has been developed to a high level 395

Fig. 19.1 The Sultanate of Oman that lies adjacent to the Arabian Sea and borders on Saudi Arabia, UAE, and Yemen 402
Fig. 19.2 There are about 120,000 camels in Oman, mostly they are on the rangelands and rely on sparse desert forage and browse 412
Fig. 19.3 Low cost materials (palm fronds and other debris) have been used to stabilize sandy areas and reduce the impact of dust and sand storms 422

Fig. 20.1 The distribution of true desert and the areas affected by desertification in North China. Note the location of desertification hot spots on some desert margins where sand encroachment is a major concern (Mao et al. 2010) ... 430
Fig. 20.2 Projected global population density in 2015 ... 431
Fig. 20.3 Trees can help to prevent sand encroachment but trees require regular watering which is costly and impractical. Plant spacing should not be too close ... 432
Fig. 20.4 Dynamics between people, livestock, cropland and desertification ... 434
Fig. 20.5 A schematic diagram representing the change in land use systems in the arid regions of northwest China. Mixed farming in this context refers to areas in which the Han system of oasis development co-exists with a less intensive agro-pastoral system ... 435
Fig. 20.6 Precipitation in Xinjiang, NW China in the 50+ years ending 2005 ... 436
Fig. 20.7 Annual rate of spread of sandification in China. In recent years the areas treated by the methods outlined in Chaps. 2 and 3 of this book have exceeded the areas succumbing to sandification ... 437
Fig. 20.8 Changes in the growth of human and livestock populations in Inner Mongolia from 1949 to 2000 ... 439
Fig. 20.9 Farming on the desert fringe in western Gansu Province, China ... 440
Fig. 20.10 Saline and sodic soils need especially adapted plants ... 440

List of Tables

Table 1.1 Major deserts and sandy lands in China 9
Table 1.2 Areas of desertified land in China classified by different processes 10

Table 2.1 The ranges of row spacing of straw and branch sand barriers 37

Table 3.1 Sowing rate of several main sand-holding species 53
Table 3.2 Suitable plant species for different sandy land types 54

Table 4.1 Area as per aridity zones of Libya 78
Table 4.2 The water situation in Libya (1990–2025) 80
Table 4.3 Important Law and Legislations regarding environment and natural resources in Libya 86

Table 5.1 Land use in Morocco 97
Table 5.2 Donor-supported projects for combating desertification in Morocco 102

Table 6.1 Potential loss of area, population and land use due to Sea Level Rise (*SLR*) over Alexandria Governorate, in the Nile Delta of Egypt 122
Table 6.2 Population expected to be displaced and loss of employment due to SLR in Alexandria Governorate 122
Table 6.3 Areas (km^2) population displaced and employment losses due to a SLR of 0.50 m in various districts of Port Said Governorate, Egypt 122
Table 6.4 Economic evaluation of beach, urban, industry, agriculture, aqua-culture areas (km^2) municipal services and transportation network (km) losses of Port Said Governorate in case of Sea Level Rise of 50 cm 123

Table 6.5 Model predictions of the impact of climate change on the Nile water budget 124

Table 10.1 Issues relating to desertification in the drylands of Niger 198

Table 12.1 Distribution of arid region in Pakistan (square kilometers) 234
Table 12.2 Current land use in Pakistan based on satellite imagery interpretation (000 ha) 236
Table 12.3 Farm size distributions in Pakistan 237
Table 12.4 Distribution of farms and farm area by tenure 237
Table 12.5 Land utilization in Pakistan (million hectare) 239
Table 12.6 Soils affected by various types of salinity and sodicity (000 ha) 241
Table 12.7 Area affected by water erosion (000 ha) 241
Table 12.8 Area affected by wind erosion (000 ha) 242
Table 12.9 Extent of water logged area (000 ha) 244

Table 13.1 Performance indicators of native and introduced of C_3/C_4 tree and shrubs species under saline conditions in Kyzul Kum 272

Table 14.1 Areas of problem soils in Myanmar 284
Table 14.2 Extent of water erosion within the dry zone of Myanmar 299
Table 14.3 Rate of soil erosion under different levels of soil cover 300

Table 15.1 The four major climate types in The Philippines 307
Table 15.2 Area distribution of erosion classes by island grouping (in million ha) 309
Table 15.3 Soil loss for various land uses and slopes (tons/hectare/year) 311
Table 15.4 List of farming and other technologies adopted by farmers in Lantapan, Bukidnon 312
Table 15.5 Scope and coverage of the Philippines National Action Plan (NAP) 319

Table 16.1 Extent of each soil erosion hazard class within the Central Province of Sri Lanka 334

Table 17.1 Most of the country is arid and hyper arid 359
Table 17.2 Key plant species of Hircanian zone (Heshmati 1999) 362
Table 17.3 Distribution of the key plant species of dryland habitats on the basis of ecological needs in Iran 366

Table 18.1 A review of available desertification control technologies in Iran 384

Table 19.1 Human population by region in Oman 412
Table 19.2 Estimated livestock number 1994 and 2005 413
Table 19.3 Current dry matter balance 413
Table 19.4 Potential dry matter balance 413

Table 21.1 Scaling-up processes (After Gillespie 2004) 447

Part I
Deserts and Desertification in China

China has made remarkable advances in controlling sand movement, mitigating the effects of dust and sand storms, developing shelter belts to protect oasis and restoring degraded lands.

The three chapters in this part begin with an overview of the location, size and characteristics of China's desert and the area impacted by desertification.

The following two chapters detail the methods used by the Chinese to combat desertification by either predominantly mechanical methods or by the use of biological agents.

Chapter 1
Introduction to Deserts and Desertified Regions in China

G. Ali Heshmati and Victor R. Squires

Synopsis This chapter provides information about the geographical location, population, climatic conditions, natural resources, areal extent and administrative regions of China, the third largest country in the world. We discuss definitions of desertification, land degradation, and the causes and hazards brought about by desertification. Finally, we provide information pertaining to the status, characteristics, types, distribution and efforts to combat desertification in China – one of the countries most seriously affected by desertification that is exacerbated by desert encroachment. We also explain the role in China's development strategy of efforts to prevent desert encroachment.

Key Points

- China is one of the developing countries with vast deserts and desertified areas and 60 % of her population is living in the affected areas. The status of desertification is very serious. It is mainly caused by climatic variations and human factors. It is estimated that 13 Mha of arable land has been threatened by disasters of wind and sand storms; about 100 Mha of steppe, desert steppe and pasture lands have been seriously degraded; thousands of water conservation facilities and systems have been threatened by wind and sand hazards and the benefits of the drainage system have been reduced; around 800 km of railway has been threatened and 1,000 km of highways have been destroyed by the accumulation of sands.

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- Deserts (P:ETP ratio <0.5) and desertified land are mainly distributed in arid, semi-arid and dry sub-humid areas, covering 13 provinces and autonomous regions in North-west China (including part of Tibet) and in Northeast China. Gobi and sandy deserts cover an area of about 1,530,000 km^2, which is equivalent to 15.9 % of the national land area. According to Zhu (1998) the existing desertified land area in China is 861,600 km^2, accounting for 8.9 % of the total land area, of which desertified land induced by water erosion covers 394,000 km^2, making up 45.7 % of the total desertified area; wind-erosion induced desertified area is 379,600 km^2, or 44.1 %; and desertified area caused by physical and chemical actions (such as secondary salinized land) occupies 88,000 km^2, or 10.2 %.
- Desertification in China should not include original desert such as sandy desert, rocky of gravel desert (gobi), salt desert, wind-erosion related yardang relief and frigid desert resulting from purely natural factors. The inclusion of the hyper-arid areas (deserts) distorts the nature of the problem of desertification and its control and reversal in China.

Keywords Land degradation • Deserts • Geographic distribution • Remediation efforts • NPP • Dust and sand storms (DSS) • Poverty • Governance • Laws • Regulations • Development strategy

1 China in Brief

1.1 Area and Administration Regions

China is located in the northern hemisphere with an area of more than 9.6 million km^2. It is 5,200 km wide from east to west and 5,500 km long from north to south. It consists of a number of provincial-level administrative regions including two special administrative regions, four municipalities directly under the central government. Twenty-three provinces and five autonomous regions under which there are 331 regional areas, cities, autonomous areas and 2,858 counties. In 2010 there were 11 cities in China with more than two million population in each.

1.1.1 Geographical Location and Population

China consists of land and ocean and lies in the eastern part of the Asian Continent. It is close to the Pacific in the eastern side and it deeply imbedded into the inland of Asia in the northwest part. It is located 3° 52′ and 31° 10′ north latitude and 73° 40′ and 135° 230′ east longitude. The neighboring countries are Korea, Mongolia, Russia, Afghanistan, Pakistan, India, Nepal, Myanmar (Burma), Vietnam, Malaysia and Indonesia. China has the largest population in the world with a total population of 1,334.7 billion by the end of 2009. The official total population figure is almost certainly an underestimate.

1.1.2 Climate and Rainfall

Climate may be divided into humid, sub-humid, semi-arid and arid belts. Average rainfall is 650 mm. The distribution is not evenly distributed across regions. The coastal areas, such as Guangdong and Fujian receive rainfall of more than 1,000 mm. In the middle and lower reaches of Yangtze rainfall River varies from 800 to 1,600 mm and averages 100 mm in the inland areas such as Xinjiang, Inner Mongolia and north west of Tibet. Areas lying on the southeast edge of Taklamakan Desert receive about 20 mm/year.

1.1.3 Natural Resources

China is endowed with more than 148 kinds of minerals. The mines that rank first in the world include wolfram, antimony, zinc, titanium, lanthanum, etc. Second rank are coal, tin, molybdenum, mercury, phosphorus etc. It has plentiful sea resources including 2,000 species of marine fish. Its fishery of coastal sea takes 1/4 of the world's catch and it is the first in the world overall, from fishing outside its territorial waters. Fauna and flora in China is plentiful including over 30,000 kinds of wild plants, 1,100 kinds of birds and more than 400 types of animals.

2 Some Terminology and Definitions

The word "desertification" was first coined by a French Scholar, A. Aubreville in 1949. In total, over 100 concepts of desertification have been defined since that time. At first, the general perception of desertification was that of expanding deserts, mainly in the Sahel region, and this is still the common public understanding of the term. Within the scientific community it is only since the 1970s that the emphasis of the term has shifted to mean "the degradation of otherwise non-desertic regions from within, rather than on an invasion from outside" (Verstraete 1986). The United Nations Convention to Combat Desertification (UNCCD) in 1994 defined "desertification" more clearly based on its formation and accelerating processes and distribution scope.

Desertification means *land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variation and human activities*. Desert regions where the P/ETP <0.05 are excluded. Strict adherence to this definition would avoid a lot of confusion (Dahlberg 1994; Reynolds et al. 2011) and put the problem of desertification in a much clearer perspective. The confusion between controlling the desert (a not unreasonable aim) and desertification control has hindered efforts in a number of countries. A consequence of misunderstanding about desertification, fuelled by the belief that desert spreading is the primary problem, is the planting of sand dunes. Planting, though costly, is technically and logistically a simple operation now perfected by years of investigation in places like Northwest China and in Iran. The benefit/cost ratio of planting is low or negative. But planting is visible and gives the impression that something is being done. It allows government agencies to avoid tackling the much harder social and economic problems of insidious land degradation. Phenomena like desertification involve environmental, economic and social factors The combined effects have either been ignored or treated in a one-sided manner. Progress in combating desertification will require a major re-think (Carrad et al. 2006) and the application of holistic approaches such as Integrated Ecosystem Management.

Land degradation means *reduction or loss of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land use or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as soil erosion caused by wind and/or water; deterioration of the physical, chemical and biological or economic properties of soil; and long-term loss of natural vegetation.*

Arid, semi-arid and dry sub-humid areas means *areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65*. Hyper-arid areas, including real deserts such as the Sahara and China's Taklamakan were excluded from the official UN definition. Their inclusion in the areas of so-called desertified land in China and in some other countries like Oman, Egypt and Libya has been a source of confusion (Squires et al. 2011).

3 China Deserts

3.1 Characteristics of China Deserts

They cover a large area, 2.674 million km^2, which is 30 % of the land area (Fig. 1.2). Climatic conditions are characterized by dry air and lack of rainfall. Annual precipitation is less than 200 mm and sometimes there is no rain at all. Due to lack of the moisture in the air, the difference of the diurnal temperature is high (reaching 30 °C). The rate of transpiration rate exceeds the rate of precipitation. It is severely cold and dry in the high altitude areas (Fig. 1.1).

China's total amount of water resources is estimated at 2.8 trillion cubic meters (m^3), and 200 m^3 per capita, only one-fourth of the world's average. China is divided into four zones in terms of natural rainfall. Firstly, the rain abundant zone, located to the south of Qilian Mts and the Yellow River (Huanghe) where precipitation is between 800 and 1,600 mm; secondly, the sub-humid area with a rainfall between 400 and 800 mm located to the north of. Qilian Mts. and the Huanghe basin; thirdly, the semi-arid zone with a rainfall ranging from 200 to 400 mm and fourthly, the

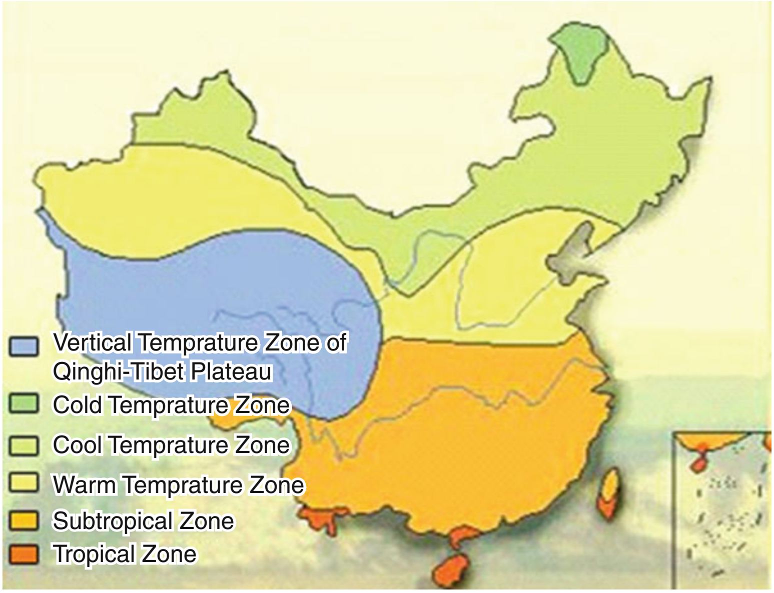

Fig. 1.1 There are several major climate zones with a high proportion of cold arid regions such as in the Qinghai-Tibet Plateau

arid zone with a rainfall less than 200 mm. The annual rainfall is about 648 mm on average, 150 mm less than the world's annual average level. The annual average run-off depth is 284 mm, 30 mm less than the world's average level. The average amount of water for 1 mu (667 m^2) is about 1,888 m^3.

The Chinese government, beginning in the 1950s, set up a large number of artificial oases in the deserts using water derived from inland rivers that arise in the snow fields of adjacent mountains and by exploiting groundwater. Groundwater recharge was severely hampered by the damming of streams. As a result of over-extraction, water tables have fallen creating cones of depletion of groundwater in a number of regions. This has led to death of riparian vegetation and increased frequency and severity of dust and sandstorms (DSS) in north-west China (Lu et al. 2002).

There are a few unique (and now endangered) plant and animal species. Total kinds of unique and ancient seed plant are only 700 – among them the desert seed plants in high altitude/frigid region. Many plant species are unique especially those in the genera *Tetraena*, *Tugarinovia* and *Stilpnolepis*. Wild horse, wild ass, wild camel, the Xinjiang red deer, the high nose antelope, the Pushi antelope etc. are some of the animals found in desert regions. The wild yak and Tibet antelope are found in the relatively high altitude regions where climatic conditions are severe.

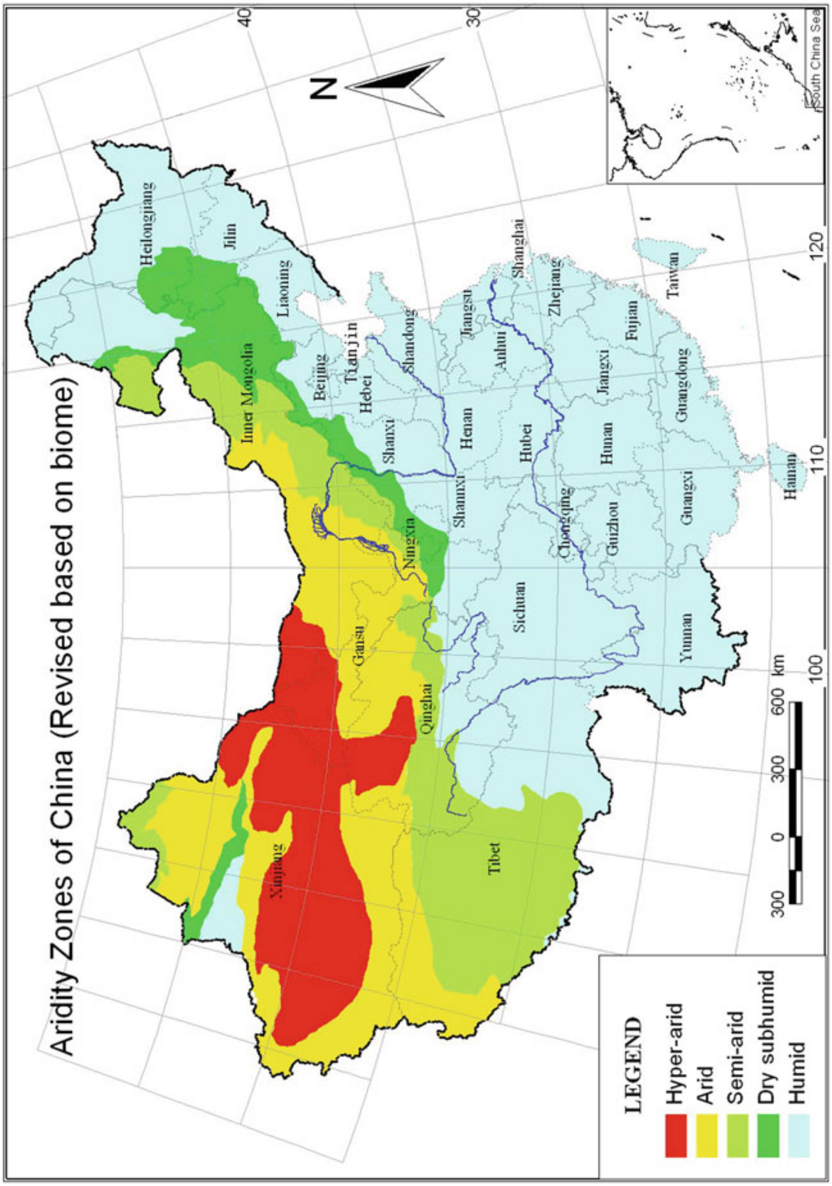

Fig. 1.2 China has a large area of true desert (hyper arid and other areas of arid land) as well as extensive areas of sandy land on dry sub humid areas (Wu et al. 2007)

Table 1.1 Major deserts and sandy lands in China

Name	Area (Km^2)	Annual rainfall (mm)	Potential evaporation (mm)
Taklamakan Sandy Desert	337,600	10–50	2,100–3,400
Guerban-Tonggute Sandy Desert	48,800	70–150	1,700–2,200
Kumutage Sandy Desert	22,800	<10	2,800–3,000
Qaidam (Chadamupendi) Desert	34,900	E50-170; W10-25	2,000–3,000
Badanjilin Sandy Desert	44,300	40–80	3,400–3,700
Tenggeli Sandy Desert	42,700	116–148	3,000–3,600
Wulanbuhe Sandy Desert	9,900	100–145	2,400–2,900
Kubuqi Sandy Desert	16,100	150–400	2,100–2,700
Keerqin Sandy Land	42,300	300–450	1,700–2,400
Hunshandake Sandy Land	21,400	E350-400; W100-200	2,000–2,700
Maowusu Sandy Land	32,100	E400-440; W250-320	2,100–2,600
Hulunbeier Sandy Land	7,200	280–400	1,400–1,900

Source: Zhang Fengchun, 2006, personal communication

Fig. 1.3 Yardangs are a type of desert landscape that is shaped by wind and water. This set is from the Qaidam (Chadamupendi) Desert (Photo V. Squires)

3.2 Types and Distribution of China's Deserts

According to their composition, the desert is divided into gravel desert, sandy desert, stone desert, salt desert and argillaceous desert etc. (Table 1.1, Fig. 1.3). The gravel desert (Gobi) is almost covered entirely by gravel and broken stones. The surface configuration of stone desert is composed of bare rock and usually formed in the mountain and piedmont belts of arid area and the surface character is bare rock and scree accumulation on the hillside.

During heavy rainfall events, the weathering gravel is moved to piedmont and forms a large scale of pluvial fan. The sandy desert by contrast has the whole surface covered by large aeolian sand.

Table 1.2 Areas of desertified land in China classified by different processes

Types of desertification	Area (km^2)	% of total
Wind erosion	379,600	44.1
Water erosion	394,000	45.7
Salinization	69,000	8.3
Engineering construction	19,000	1.9
Total	861,600	100.0

4 Desertification in China

Deserts (P:ETP ratio < 0.5) and desertified land is mainly distributed in arid, semi-arid and dry sub-humid areas, covering 13 provinces and autonomous regions in North-west China (including part of Tibet) and in Northeast China (Fig. 1.2). Gobi and sandy deserts cover an area of about 1,530,000 km^2, which is equivalent to 15.9 % of the national area (Ci and Yang 2010; Lu et al. 2005a, b). According to Zhu (1998) the existing desertified land area in China is 861,600 km^2, accounting for 8.97 % of the total land area, of which desertified land area induced by water erosion covers 394,000 km^2, making up 45.7 % of the total desertified area; wind-erosion induced desertified area is 379,600 km^2, or 44.1 %; and desertified area caused by physical and chemical actions (such as secondary salinized land) occupies 88,000 km^2, or 10.2 % (Table 1.2).

The Chinese Academy of Sciences has published a map of deserts and desertification, which shows that the total area of China's sand, gobi and stony deserts is 1.57 million km^2. China's sand deserts cover an area of 684,000 km^2, including 446,000 km^2 of shifting deserts. Most of the deserts are found in western China, covering an area of 582,000 km^2, and the east, which has deserts of 102,000 km^2, according to the map. The largest deserts include Taklimakan, Badain Jaran, Gurbantunggu, Tengger and Qaidam.

The inclusion of the hyper-arid areas (deserts) as set out in Table 1.2 distorts the nature of the problem of desertification and its control and reversal in China. Therefore, desertification in China should not include original desert such as sandy desert, rocky or gravel desert (gobi), salt desert, wind-erosion related yardang relief (Fig. 1.4) and frigid desert resulting from purely natural factors. With regard to bedrock-exposed stony hills (bare rocky relief), only the naturally formed bare rock landscape such as karstic *fenglin* (Peak forest) and *fengcong* (cluster forest) is differentiated from areas where the top soil has washed-off and bedrock exposed rocky slopeland resulting from human activities such as cultivation of steep slope for cultivation. Only the latter can be referred to as rocky desertification. In terms of water erosion related desertification, it merely means serious land degradation marked by bad land or rocky (fragmental) slopeland occurring due to a serious decline or even loss of land productivity resulting from serious fluvial erosion caused by human activities rather than simply referring to all that related to soil and water loss as desertification.

Since desertification is closely related to human activities, the time factor is important (Dahlberg 1994). Desertification refers to land degradation caused mainly

Fig. 1.4 Riparian areas like this one on the lower reaches of the ShiYang river in the Hexi corridor of China have died as a result of over enthusiastic water conservation projects that prevented annual flooding after the spring snow melt and the cessation of ground water recharge

by human activities since recorded history (Fig. 1.4) rather than taking the deserts formed and developed in natural process during prehistorical or geological periods as desertification. Therefore, desertification combating cannot be equated to sandy desert prevention and control, or even simply take the areas with drought index ranging between 0.05 ~ 0.65 as desertified area.

That being said, there is an important role for preventing and controlling desert encroachment and the chapters that follow will outline measures being taken to do this important work.

4.1 Status and Causes of Desertification

China is one of the developing countries with vast deserts and desertified areas and 60 % of her population is living in the affected areas. The status of desertification is very serious (Ci and Yang 2010). It is mainly caused by climatic variations and human factors. It is estimated that 13 Mha of arable land has been threatened by disasters of wind and sand storms; about 100 Mha of steppe, desert steppe and pasture lands have been seriously degraded; thousands of water conservation facilities and systems have been threatened by wind and sand hazards and the benefits of the drainage system have been reduced; around 800 km of railway has been threatened and thousands km of highways have been destroyed by the accumulation of sands.

4.1.1 Causes of Desertification

Desertification is mainly caused by climate variation and human factors. Human factors are the major elements involved in accelerated land degradation including population growth, unsustainable economic development, poor environmental and ecological awareness, over-cultivation and improper conversion of rangelands for cropping, mis-management of water resources, overgrazing, unsustainable exploitation of fuel wood and uncontrolled collection of herbal medicines, deforestation and shifting cultivation, terrace cropping on slopes and hilly areas, salinization/alkalization, oil exploration and mineral mining.

Desertification does not refer to the expansion of existing deserts (Squires 2003). It occurs because dry land ecosystems, which cover over one third of the world's land area, are extremely vulnerable to over-exploitation and inappropriate land use practices. Poverty, political instability, deforestation, overgrazing and poor irrigation practices can all undermine the land's productivities. Climate change is now believed to contribute also (Reynolds and Stafford Smith 2002).

4.1.2 The Processes of Land Degradation

Desertification often results from the degradation of the vegetation cover by overgrazing, over trampling, fuelwood collection, repeated burning, or inappropriate agricultural practices. It leads to a general decrease in productivity of the land and in accelerated degradation of the soil resource due to soil erosion (both by wind and water), siltation, salinization and alkalinization of irrigated lands, or dryland salting. The excessive loss of soil nutrients, and sometimes depletion of the soil seed bank, affects the capacity of the vegetation to recover and constitutes the principal mechanism of irreversible damage to the environment (Squires 2010a, b). The impact of grazing on pastoral rangelands is explained more fully in Li (2010).

4.2 Consequences of Desertification

China has been severely hit by persistent drought and desertification. Related natural catastrophes, such as sand-dust storms are increasingly becoming a matter for national and international concern (Yang et al. 2002). Hazards of desertification in China are serious.

Desertification is generally conceived as a much wider concept than drought, involving not only water availability issues, but also various forms of soil degradation, loss of biological productivity, and a host of human impacts. Desertification must be distinguished from drought. The combination of progressive desertification and drought can be severely crippling to the environment, as the stress created by human overexploitation of the land becomes especially visible during severe drought. Droughts and desertification can amplify each other's impacts and the resulting

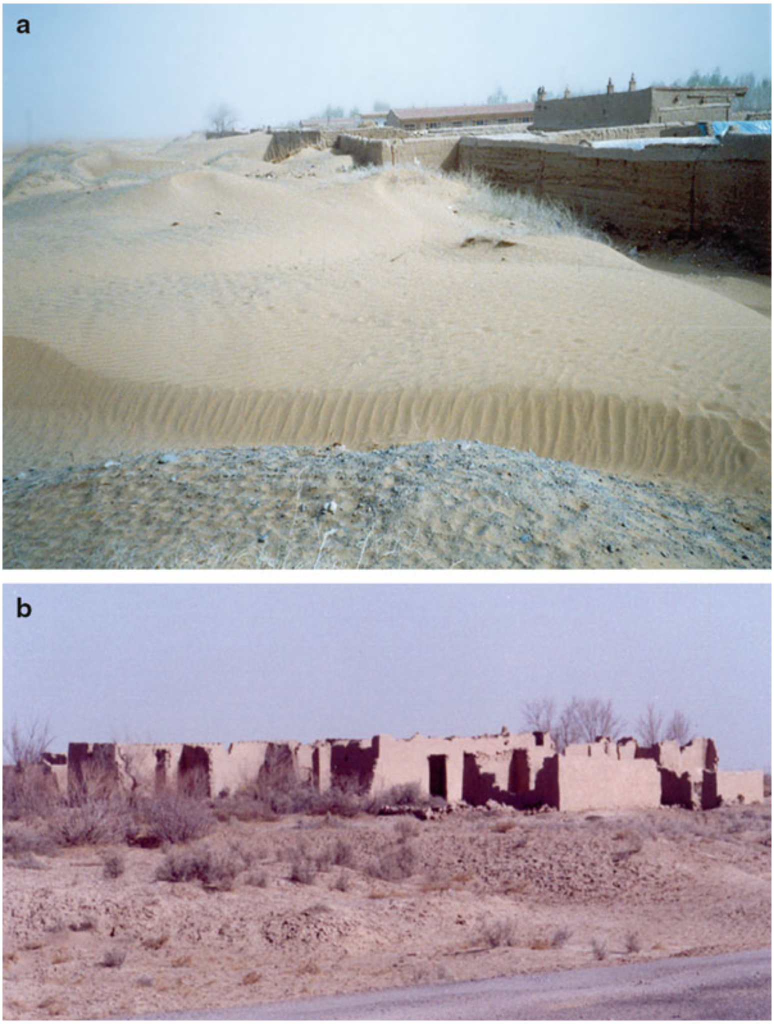

Fig. 1.5 Sand encroachment and accelerated desertification is forcing villagers to abandon their homes and migrate to other regions (Photos Victor Squires)

degradation of the environment can further affect adjacent areas, either directly (invading sand dunes, siltation of dams downstream) or indirectly (migration of population), increased international tensions over increasingly scarce resources (Fig. 1.5).

The intensity of desertification processes can vary from slight to very severe in terms of degradation of plant and soil resources. Different processes and interactions take place in different ecosystems, but the general tendency is towards degradation that results from the interplay of these processes and interactions are common to all situations. In that sense, desertification, which has been called the 'cancer of drylands' can affect any area which has been made vulnerable enough by climatic stress or human overexploitation, or both.

The area of land affected by wind erosion exceeds the total area tilled. Annually, there are about 13 million ha (Mha) of cropping lands threatened by wind and severe dust and sand storms causing a decrease in crop yield, loss of livestock and property damage. It is also estimated that nearly 100 million ha of rangeland has been impacted by the severe wind erosion incidents (Ci and Yang 2010; Wang et al. 2012). Over a thousand water conservation facilities were destroyed by sand movements. Similarly, a total of 800 km. of railway lines and several thousand km of highways in desert regions are impacted by sand accumulation and wind hazards. Economic loss is estimated at 6.5 billion USD annually and affects 400 million people (Wang et al. 2012).

Water erosion is also serious. It is estimated that 430,000 km^2 of the Loess Plateau is affected by soil loss and water erosion. The other negative consequences caused by desertification include rapid reduction of the area of arable lands, and subsequent impact on human populations; rapid decrease in land productivity, the degradation of ecosystem and decline of biodiversity. Other impacts are constraints to economic and social sustainable development and unemployment in the affected areas; aggravated poverty and poor quality of life, outward migration, and hunger in the affected areas; imbalance and shortage of water resources and frequent changes in the ecosystem complex and influences of sand transport and long-distance dust carried in the atmosphere to the east and the southeast parts of China (Squires 2007).

5 Combating Desertification in China

Combating desertification is essential to ensuring the long-term productivity of inhabited dry lands. Unfortunately, past efforts have too often failed, and all around the world the problem of land degradation continues to worsen although some countries are making progress in arresting and reversing it (Yang et al. 2011).

As a large country with dense population and complex environmental conditions, China is aware that desertification combating is also of importance to global sustainable development of environment and economy. Through a long period of hard efforts to combat desertification, capacity has been built through technology know-how whereby technicians and scientists have been trained. Combating desertification includes activities which are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development which are aimed at: (i) prevention and/or reduction of land degradation; (ii) rehabilitation of partly degraded land; and (iii) reclamation of desertified land.

In the 1950s, the Government of China conducted scientific surveys and studies on affected lands and has given priority to combating desertification in seriously impacted regions. Since 1970s, China has initiated and implemented successfully such major ecological restoration projects such as the Three North Regions Shelter

Belt Development Project, the Coastal Protection Shelter Belt Project, The National Action Program to Combat Desertification, the Plain Farmland Protective Networks project and the Green Belt Establishment Project along the Middle and Upper stream of the Yellow River (Ci and Yang 2010).

The strategic objectives to combat desertification are divided into three phases. Firstly (1996–2000) was to slow down the speed of desertification; improve the ecosystem in some regions; increase peoples' standards of living; rehabilitate 3.177 Mha of lands affected by wind erosion etc.; secondly (2001–2010) is to improve ecological conditions in some regions with set targets and thirdly (2011–2050), is to bring under control nearly all the desertified lands. The last phase coincides with the time schedule of China National Economic and Social Developmental Plan.

5.1 United Nations Convention to Combat Desertification (UNCCD)

Recognizing the linkages between poverty and environmental degradation, the United Nations Convention to Combat Desertification (UNCCD) was established in the wake of the 1992 Earth Summit in Rio de Janeiro. The UNCCD is the first international treaty to:

- Address the issues of poverty and environmental degradation in rural areas, particularly in Africa,
- Recognize that grassroots resource users are central to identifying and implementing solutions,
- Adopt a bottom-up approach, involving the active participation of women as well as men in the local communities, in all phases of the development process
- Call for an innovative mechanism - the Global Mechanism - to mobilize substantial resources, through partnership at all levels and to
- Emphasize the need for an integrated approach to combating desertification. In the spirit of the UNCCD, "combating desertification" includes activities that are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development which are aimed at prevention and/or reduction of land degradation; rehabilitation of partly degraded land and reclamation of desertified land (UNCCD 2007).

5.2 National Action Program (NAP)

To implement the UNCCD, Chinese Government has set up the China National Committee for Implementing the United Nations Convention to Combat Desertification. This is composed of 16 ministries and commissions. This Committee is also responsible for the inter-cooperation and coordination among ministries and governmental administrative agencies for sound implementation of the National Action Programs to Combat Desertification.

Since the 1990s, the NAP to Combat Desertification (NAP) and the Three North Region Shelter Belt Development Project have brought more than 16 million ha of farmland and 10 million ha of rangeland under effective protection. Despite the great progress in combating desertification, great challenges remain. Desertification has become a bottleneck for the social and economic development and improvement of the local population living standards in the affected regions. Thus combating desertification in China is of great and far-reaching significance. It is a must not only for sustainable social and economic development within the country, but also for improvement of the regional and global environment (Lu et al. 2005a, b, Wang et al. 2012).

- *Main Projects in the National Action Programs to Combat Desertification*: According to the ecological requirements of the sustainable development strategy, China has emphasized her efforts on a significant number of projects to combat desertification whereby the following principles will be applied:
  - Priority be given to protective measures,
  - Techniques adopted should be suitable to local conditions,
  - Management of key projects be rationalized,
  - Implementation of projects be divided into phases with an appropriate time frame,
  - Supervising and monitoring be strengthened and
  - Great attention is paid to cost/benefit.

Desertification combating is a long and difficult task dealing with multidisciplinary studies and engineering fields. Along with the domestic efforts to combat desertification, the Chinese Government is anxious to cooperate with international organizations. It is also ready to work together with all countries. China also would like to share her scientific results and practical experiences to combat desertification with the world. China is willing to cooperate with international societies through bilateral and multilateral channel, to get financial assistance if it is available (Box 1.1).

Box 1.1: Examples of International Collaborative Efforts to Combat Desertification (Source: Wang Jihe (2006, personal communication))

UNDP Science and Technology Fund Project: in 1988, it provided China a set of advanced drip-irrigation equipment from Israel. The implementation of this project found a new way for the water-saving irrigation in desert areas.

(continued)

Box 1.1 (continued)

Yellow sand control project: it is a Sino-Korea cooperation project and started in 1996. This project, funded by Korea, focused on the observation and research of desert control technologies and the protective effect of windbreak.

Application of *Ludile* on sand-fixation plant project: it was a Sino-Japan cooperation project. *Ludile*, is a kind of liquid compound fertilizer with high efficiency. It was widely applied to wheat, corn, vegetables, melons and fruits in parts of north China. It is strong in absorption and good in granular formation and can raise yield highly. Through the application to desert plants, it is proved to be very useful in intensifying granular structure and improving soil fertility.

Gansu Integrated Desert Control and Sustainable Agriculture Project: It is a UNDP donor-assisted Project aimed at introduction and assembly of advanced domestic and overseas technologies to reverse desertification and develop the sustainable agriculture. Through the implementation of the project, great advances in equipment introduction, personnel staff training, establishment of integrated demonstration county, introduction and extension of new technologies and species, monitoring of changes of desertification and rangeland management have been made.

LAS Project: started in 1999, is a Sino-Holland project. Through the determination of such factors as sun radiation, short-wave radiation, average cloud thickness, atmosphere pressure and rainfall with LAS, water balance in Minqin desert area can be monitored. This project is still on-going.

5.3 Gansu Desert Control Research Institute (GDCRI) and Its Mandate in Desert Combating

GDCRI was established in 1959. It is the earliest research institute involved in desert control in China. It focuses on theoretical and technical research on desertification combating and ecological restoration in desert areas. It mainly deals with research and extension of technologies on controlling sand encroachment and combating desertification, exploration of new measures for protection and integrated utilization of desert resources with a view to offering technical assistance for the integrated desert control and sustainable development of agriculture, forestry and animal husbandry in desert areas. The work of the GDCRI in the early years was about "pushing back the desert", 'taming the desert' and other activities unrelated to desertification control (see Chap. 20 for a discussion of the implications of this confusion about roles).

6 Conclusions

Deserts in NW China were formed by the climatic influence of the Tibetan Plateau, Qilian , Kunlun and Tian Shan mountains and the effect of distance from the sea. Desertification processes, on the other hand, have been mainly influenced by human factors (Squires et al. 2010). Factors such as population growth, unsustainable economic development, inadequate environmental and ecological awareness, over-cultivation and rangeland encroachment for cropping productivity and overgrazing played important roles. Mismanagement of water resources and over exploitation of ground water leading to a lowering of water tables and salinization/ alkalization caused widespread desertification (Li and Squires 2010; Jin and Zhu 2010). Deforestation, terrace cropping on slopes and hilly areas as well as oil exploration and mineral mining have also contributed. All these factors have led to recurrent movements of sand dunes, sand and dust storms to an extent that settlements, water bodies, farmlands, road and rail networks can be totally submerged in the sand and oases area greatly reduced directly or indirectly affecting the economic and social fabric of the country (Yang et al. 2002; Squires and Yang 2010).

Fundamental strategies to combat desertification include public awareness raising, education on combating desertification, consolidation of legal knowledge, amplification of enforcement of laws, improvement of laws and regulations, enhancement of the effects to combat desertification by applying advanced science and technology and training professional personnel, promotion of sustainable development through rational utilization of resources and preparation of preferential policies and increased funding.

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Chapter 2
Controlling Sand Movement Through Mechanical Measures: China's Experience

G. Ali Heshmati

Synopsis This chapter is an overview of the measures taken to stabilize mobile sand to protect farmland, and infrastructure such as roads, railway tracks and irrigation canals. The chapter explains in detail the various proven practices accumulated from years of trial and error and derived from scientific investigation in China's extensive sandy lands.

Key Points

- China is one of the states facing serious problems of desertification in the world. The affected lands are mainly distributed in arid semi- arid and dry sub humid areas in the west part of Northeast China, North Central China and the most part of Northwest China. Shifting sand is one of the serious contributors to desertification in China.
- China has developed very successful measures to stabilize shifting sands and revegetate denuded areas. These technologies have been tested under extremely difficult conditions in China's arid north west and are now used with equal success throughout the world.
- There are two complementary measures used to fix shifting sands. One is to protect the vegetation on the sand dunes or where such vegetation has deteriorated, to plant trees, shrubs and grasses (see Chap. 3). This type is known as biological or plant measures. The other method depends on mechanical measures. These are used to set up barriers on sand dunes or to cover the surface of sand dunes by wheat straw, clay, and branches of trees, bamboo, reeds, sorghum stalks, cobblestone, and petroleum chemicals and so on. Mechanical measures have been proven to be effective in fixing shifting sand dunes. However, their success is limited to a number of years, hence; they should be complemented

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with other measures, especially the biological measures. This is where suitable desert plant species are planted immediately after the shifting sand is fixed so that permanent solutions can be attained.

Keywords Desertification • Mechanical measures • Sand dunes • Wind erosion • Land use change • Checker boards • Wind velocity • Transport routes • Infrastructure • Shapotou • Xinjiang • Gansu • Ningxia • Inner Mongolia • Tennger/Tengeli desert • Taklamakan desert • Gobi desert • Yellow river • Qilian mountain

1 Introduction

Shifting sand is one of the serious contributors to desertification in China (Ci and Yang 2010). There are two complementary measures used to fix shifting sands. One is to protect the vegetation on the sand dunes or, where such vegetation has deteriorated, to plant trees, shrubs and grasses. This type is known as the biological approach and is dealt with in Chap. 3. The other method relies on mechanical measure and is the subject of this chapter.

Sand dunes especially along the fringe of sandy desert encroachment seriously harms or threatens farmland, villages, irrigation canals, reservoirs, transportation (highway, railway), mining, etc. It is in these areas that mechanical measures are suitable as emergency measures to fight against the moving sand dunes. Mechanical measures are preferable to biological ones under these circumstances. In some extremely arid areas, subject to wind and sand movement, plants can barely survive and grow and so in order to prevent sand dune encroachment, mechanical measures must be taken. If it is desirable to plant trees, shrubs or grasses on the sand dunes in some areas, mechanical measures should be taken before planting of trees, shrubs or grasses. Otherwise the seeds or seedlings of the plants will be exposed by wind or buried by blown sand even if the soil moisture content is available and other natural factors are suitable for the plants. Mechanical measures, under these conditions, can prevent sand dunes from moving and guarantee the survival of these seedlings of the sand-holding plant species.

2 Relationship Between Mechanical Measures and Biological (Plant) Measures

In general, the service life of mechanical measures is about 3–5 years. They require regular maintenance after they are set-up. In any case, the effectiveness of desert control by biological (plant) measures alone is not satisfactory. Therefore, various sand-holding plant species should be planted after the mechanical measures. In the ensuing years, especially the first 5 years, these two measures can well be complimentary in checking wind and controlling sand (Fig. 2.1).

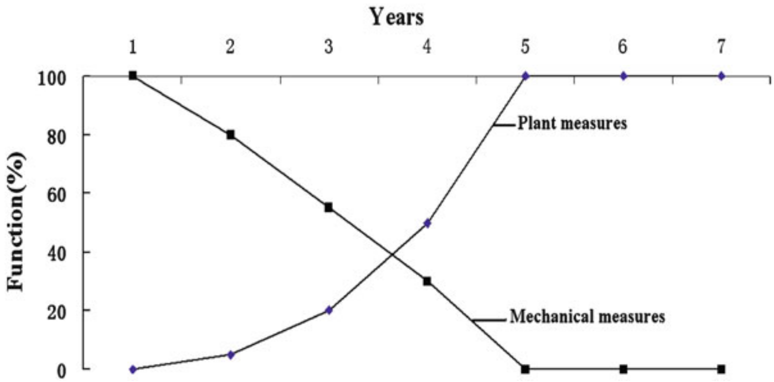


Fig. 2.1 Relationship between mechanical and biological measures

2.1 Types of Mechanical Measures and Their Uses

Modern classification of mechanical measure is generally based on the materials used, the methods of installation, the disposal pattern for the trapped sand, and the height, structure and function of the mechanical measures. Mechanical measures can be categorized into surface (covering) sand barriers and standing sand barriers. The types of mechanical measures and their functions are summarized in the Fig. 2.2.

3 Surface Sand Barriers

The movement of sand dunes needs two prerequisites. They are (1) power source – wind and (2) substance source – sand. When the wind (velocity >4.5 m/s) blows over the loose surface of the sandy land or sand dune, it will become sand-driving wind because some sand is entrained (lifted by the wind). This sand-driving wind is harmful as it will bury or damage crops or other objects. Measures to prevent such damage can be taken by covering the surface of the sand dunes. The principle of the surface barrier is to eliminate one of the above two prerequisites – substance source sand. When the wind passes over a sandy area, where a surface barrier has been set up, there will be no sand-driving wind formed.

The materials of surface barriers include straws and stalks of some crops, branches of trees, cobble stone, clay, earth, emulsified asphalt, asphalt belt and many kinds of complex polymers. The function of the barriers is to stabilize the moving sand on the spot because the sand is fixed and the passing wind is separated from the sand.

In many sandy areas of China, sections of sand dunes and oasis are distributed in a checker board pattern. These scattered sand dunes seriously threaten the farmlands of the oasis. In these circumstances, the laying of sand barriers, which are made

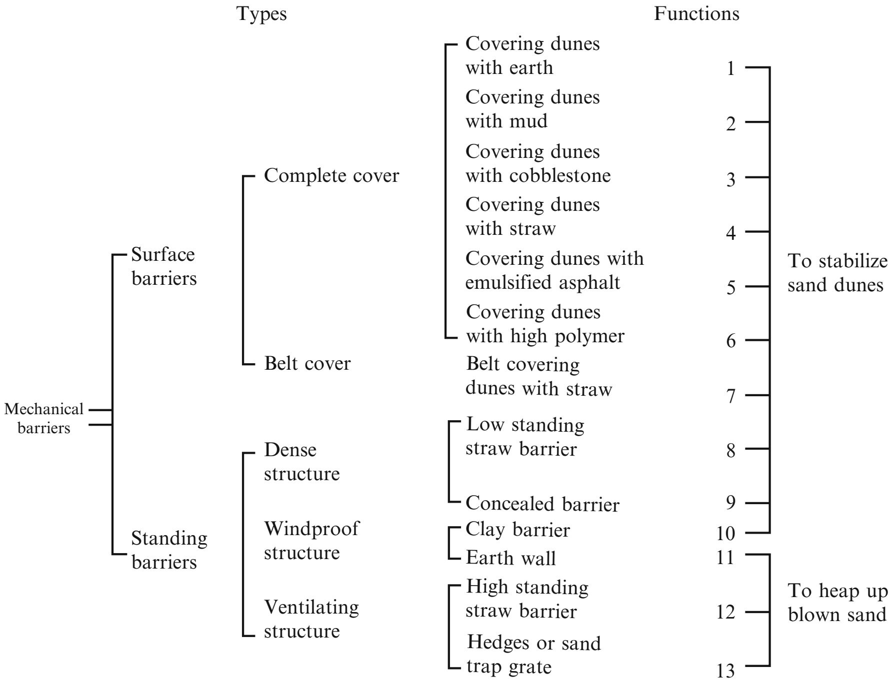


Fig. 2.2 Type of mechanical measure and its function

of local materials-straws, stalks, earth clay cobble stones among others is usually adopted. The cost of setting up such barriers is low as all the material for setting the barriers are abundant and locally available. This means that surface sand barriers can be easily utilized in such areas.

In controlling sand in some priority projects for example sand control for railway lines, emulsified asphalt has been used. However, this material is not locally available and its cost is relatively high. It is therefore not a suitable choice for general use. The following are some common surface barriers materials used in China.

3.1 Covering Sand Dunes with Earth or Mud

Local people living in the sandy areas cover sand dunes with earth or mud. The main function of the barriers is to protect agricultural production by stabilizing a sand dune that threatens adjoining agricultural land.

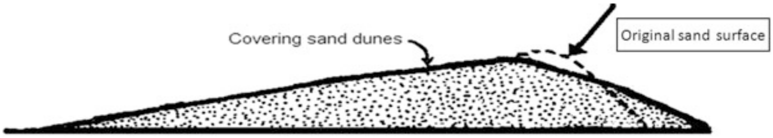


Fig. 2.3 The cross section of covering sand dune with earth

3.1.1 Technique of Covering Sand Dune with Earth

This technique uses the following steps:

- The sand top is pushed down the leeward slope to make the sand dunes gentle so that the earth can stay on the sand dunes.
- The surface of the sand dune is covered with clay or piled from the top to the foot of the sand dunes. The depth of the clay or pile covering on the sand dune is around 6–15 cm. Under normal conditions; it is deeper on the windward slope and the upper part of the sand dunes. The sand dune must be completely covered and the clay or piled soil is left loose. Some plants such as *Artemisia arenaria* and *Agriophyllum squarrosum*, can be sown after the sand dunes are covered. At the same time, several lines of trees or shrubs should be planted along the foot of the sand dunes so as to stabilize the sand dune permanently. See Chap. 3.

Covering sand dunes with mud is often practiced in areas where plants survival is problematic due to extreme shortages of rainfall. The function of the mud is to reinforce the sand surface and protect the sand dunes from erosion.

3.1.2 Technique of Covering Sand Dunes with Mud

The technique of covering the sand dunes with mud is basically the same as that of covering the dune with earth. Generally the steps of employing the earth or mud barrier are as follows:

- Cover the sand dunes with earth or damp soil
- Cover the earth or damp soil with mud alone or mud mixed with broken straws
- Daub plaster on the sand dunes from the top to the foot of the sand dunes.

A protective crust, on which there will be no plants, will be formed. Finally, trees and shrubs can be densely planted along the foot of the sand dunes. Although this method can consume a lot of man-hours it can save many useful materials and it can control moving sand dunes immediately.

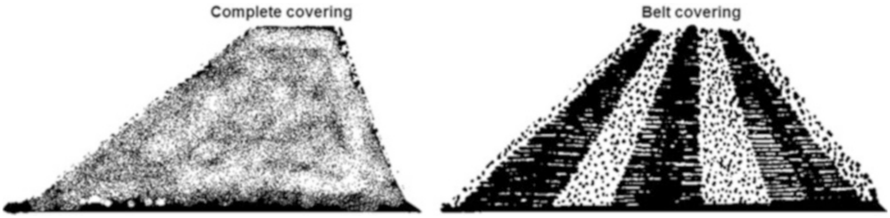


Fig. 2.4 Covering sand dunes with straw or branches

3.2 Covering the Sand Dunes with Straw or Branches

This method involves covering the sand dunes densely with straw or branches. It is usually used in areas where straws or branches are abundant. For this method, there are two types of covering sand dunes: (1) complete covering and (2) belt covering (Fig. 2.4).

3.2.1 Complete Covering

The sand dunes are completely covered with straws or branches and then sand is placed on the straws and branches, or they are held down with some big branches across them. The advantage of this type of sand barrier is that it can stabilize the sand dunes completely. Its shortcomings are that it will consume a lot of materials (approximately 370 kg of straws per hectare) and it is inimical to the growth of sand plants because the moisture conditions of dunes protected by this kind of barrier are unfavorable.

3.2.2 Belt (Strip) Covering

Here the dunes are covered with strips or belt of straws or other plant matter. The widths of the belt are varied. In general, the width is the same as the length of the straws or branches used in the barrier, that is, 50–100 cm. The row spacing is about 3 m. The run of the belt should be at right angles to the direction of the prevailing wind. In order to prevent the belt barrier from being blown away by the wind, the barrier should be covered with sand along the central line of the belt.

3.3 Covering Sand Dunes with Other Materials

In areas where clay is in short supply but cobblestone, baijang soil (clay pan or plano soil) and gypsum are abundant and available, this kind of sand barrier is often adopted.

3.3.1 Covering Sand Dunes with Cobblestones

The principle and the method of covering sand dunes with cobblestone or gravel are the same as for covering dunes with earth, but the depth of the covering using these materials is around 3 cm, not 6–16 cm.

3.3.2 Covering Sand Dunes with Baijang Soil

Covering sand dunes with baijang soil is usually used in those areas which are near a lake basin because baijang soil is commonly located in lake basin. The techniques are as follows:

- Mix the baijang soil with water
- Spread the baijang soil mixture onto the surface of the dunes. A very firm crust will be formed after the baijang soil is dry because baijang soil will cement the surface sand together.

3.3.3 Covering Sand Dunes with Gypsum

Covering sand dunes with gypsum is usually used in areas where gypsum is abundant. The establishing method is as follows:

- make plaster of paris into slabs
- crush the plaster of paris into powder
- mix the plaster of paris and sand, the ratio of plaster to sand is 7:3
- Spread the mixture into the surface of the sand dunes evenly
- Spray water on the mixture. A crust with depth of 2–3 cm will form on the surface of the sand dunes after the mixture is dry.

Among the above three kinds of barriers, the erosion resistance of the cobblestone or gravel surface is the best, and the service of the cobblestone or gravel sand barrier is the strongest. The other two kinds of sand barriers are liable to be destroyed by livestock, people or rain.

3.3.4 Covering Sand Dunes with Man-Made Materials and Chemical Stabilizers

This measure involves laying or spraying chemicals on the surface of moving sand to form a surface crust or permeate the chemical substance into the sand, then a cohesion layer will come into being, which can stop sand from drifting or moving. Sand-fixation of this kind has been trialled, especially the use of pitch emulsion, compounded chemical emulsion of wild plants, and animal's glue. Some achievements have been gained and the results showed that the method of using pitch emulsion (asphalt) is the best. However, with the high cost and lack of source, it cannot be extended on a large scale. Other materials tested are in the following models:

- In Taklimakan Desert, Chinese oil gas farms made trials of some man-made materials to cover the moving sand surface around oil gas facilities, along the expressway and tent settlements. These materials include: used plastics, poly-fiber, nylon and acrylic wire netting, oil based products and straw matrix.
- In Dunhuang, acrylic netting and nylon cloths are used to cover sand surfaces to protect the ancient Buddhist Grottoes of Magao.
- In Zhongwei County, Ningxia Hui Autonomous Region, some chemicals were adapted to fix shifting sand surfaces. The chemicals include: asphalt emulsion, OT-asphalt, ABS asphalt emulsion, OP-asphalt emulsion, Polyacylamide, Polyvinyl alcohol, Polyvinyl acetate, Hydrolytical polyacrylonitrite, and sodium silicate.

4 Standing Sand Barriers

If surface sand barriers affect one prerequisite of sand movement, standing sand barrier affect the other, namely wind. Wind velocity is reduced when any barriers obstructs the wind and some of the sand carried by the wind will heap up around the barriers when the wind velocity is reduced. The sand carrying capacity of the sand-driving wind is reduced by a big margin. According to studies on the structures of the sand-driving wind, 80–90 % of the total sand capacity of the sand-driving wind is found at the height of 20–30 cm above the ground and within this height of 20–30 cm, most of the sand is carried under a height of 10 cm above the ground. For this reason, if the standing barriers set up in the path of the sand-driving wind maintains a height of between 30–50 and 100 cm, most of the blown sand can be controlled. We can let the sand be carried by the sand-driving wind to heap up at the designated places through the setting-up of standing barriers. The dropped sand around the barriers will remain there because the wind velocity is reduced both behind and in front of the barriers, and the threat of the sand to any object can be eliminated by such standing sand barriers.

The weak wind areas formed on the leeward side and on part of the windward side of the sand barrier can allow the sand carried by the sand-driving wind to drop down and become fixed. Plantation on the bare surface of the sand dunes can be guaranteed because the standing sand barriers eliminate the sand-driving wind. Standing sand barriers, which are 50–100 cm high, are called high standing sand barriers. Standing sand barriers whose height is between 20 and 30 cm are called low standing sand barriers. Materials used for standing sand barriers, in general, are the following: straws or stalks of crops, tree branches, clay, and many other materials. Sand barriers made of any of these materials can reduce the wind velocity and heap up or stabilize the sand around the sand barriers. Standing sand barriers can

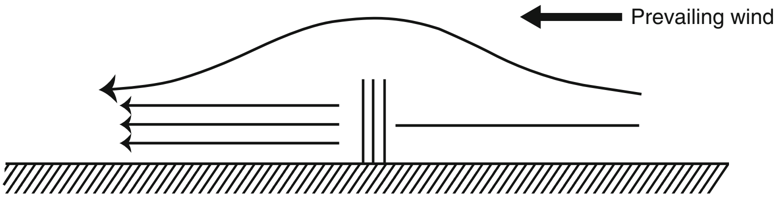


Fig. 2.5 The effect of ventilation sand barrier on sand-driving wind

be divided into different types on the basis of the materials, structure and patterns. These are *ventilating sand barriers* and *dense structure sand barriers* that have different functions in combating sand damage.

4.1 Ventilating Sand Barriers

When the sand-driving wind passes through ventilating sand barriers, the frictional drag is increased and will form separate turbulent flow and vortex flow around the barriers. The sand-transporting capacity of the sand-driving wind will be reduced because of the decrease in the kinetic energy and in the velocity of the wind through the interaction of the two kinds of flow. The sand will heap up on the windward and leeward sides of the sand barrier. The dropped sand on the windward side of the sand barrier is much less than that on the leeward side, so the sand barrier is not apt to be buried by the dropped sand. On the leeward side of the sand barrier, the mound of the dropped sand gently spreads with the wind and the mounded range. Grain size of the dropped sand is much larger than that of the windward side. So the ventilating sand barrier can act on sand-control for a long time and can stop a great deal of sand on the leeward side of the sand barrier (Fig. 2.5).

The phenomenon of sand-control differs with the different densities of the ventilating sand barriers, the space on the barrier and the level of ventilation. In general, the ratio of the area of the space on the barrier to the total area of the barrier is called the degree of density of the sand barrier. The degree of density of a sand barrier is generally regarded as the index of the sand-control efficiency of the sand barrier. When the degree of density of a sand barrier is about 25 %, it can heap up sand, on the leeward of the barrier, within a range of 7–8 times the height of the sand barrier. When the degree of density reaches 50 %, the range of the dropped sand on the leeward of the barrier is around 12–13 times the height of the sand barrier. As the degree of density of the sand barrier increases, the range of the dropped sand, the amount of dropped sand mound and the sand-control capacity of the sand barrier will rise. But when the degree of density of a sand barrier exceeds 50 %, wind erosion at the windward side of the sand barrier may occur, and under these circumstances, the sand barrier may be destroyed from the base. In order to make optimum use of sand barriers, the height, the row spacing and the degree of density of sand barriers should be determined in the light of specific conditions.

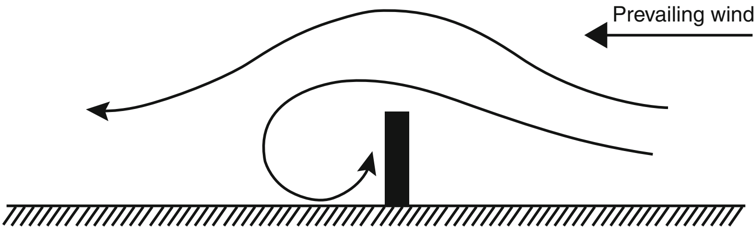


Fig. 2.6 The effect of dense structural and windproof sand barriers on sand-driving wind

The degree of density of a sand barrier suitable for a given area can be determined in accordance with the wind force and the abundance of the sand in the area. Under normal conditions, ventilating sand barriers whose degree of density is between 25 and 50 % are usually adopted in dune control. In an area where the wind force is strong and the sand is abundant, the degree of density of the sand barrier should be greater than normal; conversely, in an area where the wind force is weak and the sand not so abundant, the degree should be smaller than normal.

The sand control function of the standing sand barrier is satisfactory because it not only can stop the sand carried by the sand-driving wind, but also can stabilize the sand which is originally located around the barriers. The standing sand barriers can gradually gather many small sand dunes or sand mounds into one big dune and form a "sand-hold-back" sand dam or sand mountain. Standing sand barriers are often adopted to protect farmlands, canals, transport lines and wind gaps, which are seriously threatened by the moving sand, In order to prevent the protected objects from being buried by sand dropped from the sand-driving wind, a suitable distance must be kept between the sand barriers and the protected objects. This distance can be determined according to the degree of density and the range of dropped sand of the sand barriers.

4.2 Dense Structural Sand Barriers

A strong vortex flow will form around the sand barrier that is completely windproof or structurally dense because the sand-driving wind is raised upon the windward side and descends sharply on the leeward of the barrier when the sand-driving wind is obstructed by such a sand barrier. Because the vortex flows formed around the sand barrier affect each other, the kinetic energy of the blown sand is greatly consumed and both the wind velocity and the sand-transporting capacity of the wind are reduced. The sand carried by the sand-bearing wind will heap up around the sand barriers (Fig. 2.6).

If the sand is very abundant, the height of the dropped sand will be rapidly equal to the height of the sand barrier. In this case, the sand barrier is liable to be buried by the dropped sand, so the service life of a barrier, in this condition, is very short,

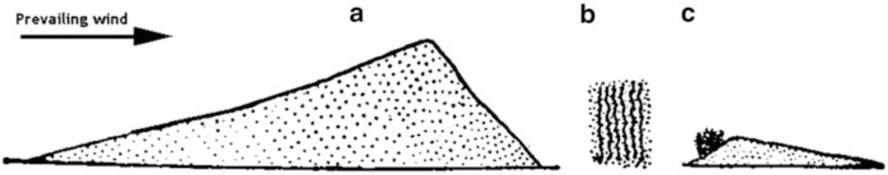


Fig. 2.7 The indication of the prevailing wind (**a**) is the initial condition after stabilizing the dune with standing sand barriers (**b**) is the location of plantings of trees and shrubs between the dunes and (**c**) the reduced size of the dune at some future time

however, the base of this type of barrier is not liable to be destroyed, and a steady surface of sand between two sand barriers will soon be formed. This phenomenon can protect the seedlings of plants seeded on the sand dunes where the sand barrier is set up. In order to avoid the seedlings of sand plant being buried by the shifting sand on the leeward side of the barrier, the plantation site between two sand barriers should be kept at a distance from the sand barrier. The low windproof or dense structural sand barriers should be installed before the planting of vegetation between sand barriers is started.

4.3 Installation of Standing Sand Barrier

Standing sand barrier are the most widely used in sand-control, especially the straw sand barriers that have often been adopted by local people to protect farmlands and irrigation canals. To protect railway lines and major infrastructure located in the sand areas, hedges of wood chips are usually used, and along the fringes of the villages or farmland, sand-protecting walls of earth are often adopted by local people. In recent years, clay sand barrier, which belong to the low windproof sand barrier type, have been widely used in desert areas. Techniques for installing various standing sand barriers are described in the following section:

4.3.1 Run of Standing Sand Barriers

The run as well as the disposing patterns of a standing sand barrier should be determined in the light of the direction of the prevailing wind, the patterns (shapes) of sand dunes and the purpose of the sand barriers. The run of a sand barrier should meet the direction of the prevailing wind at right angles. Therefore, the direction of the prevailing wind in the area that is to be protected must first be found out. According to the practical experience, there are three indicators: (A) the length of the windward slope and the leeward slope of existing sand dunes; (B) the patterns of sand ripples; (C) the run of sand plaits (Fig. 2.7).

On the work site, the run of the sand barrier can be determined in the light of the above-mentioned indicators. The windward slope of sand dunes is longer and gentle,

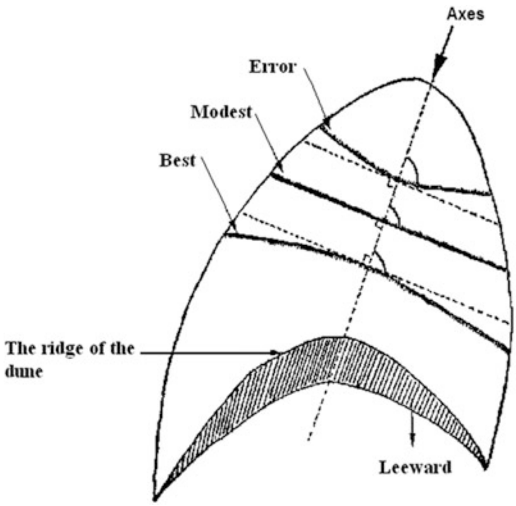


Fig. 2.8 The run of sand barrier on the windward slope of dunes

and the leeward slope is shorter and steep. From this phenomenon, the direction of the prevailing wind can be easily seen but for micro landscapes, the directions of the wind are various, and in this case we need to consult patterns of sand ripples. The run of the ripples formed by the coarse sands on the surface of sand dunes is perpendicular to the direction of the prevailing wind. These ripples can clearly show us the direction of the prevailing wind, so sand barriers can be set up along the run of the ripples of coarse sands. Ripples of fine sand formed between the ripples of coarse sands, caused by partial changes of the direction of the prevailing wind should not be regarded as indicators of the direction of the prevailing wind. In general, the third indicator, the run of sand plaits, is more reliable than the previous two. Because the spreading direction of the sand plait is identical with the direction of the prevailing wind, this direction can be recognized through an observation of the run of sand plaits.

The run of the sand barrier should be kept at right angles to the direction of the prevailing wind. When a sand barrier is planned for the windward slope of existing sand dunes, a line, which goes along the axis of the sand dune, should be first drawn in line with the prevailing wind. For practical purposes, the angle between the run of the sand barrier and this line should be more than 90° because of the distribution patterns of the wind on the sand dune. The wind is stronger in the middle (top) than on the two sides. If the angle between the run of the sand barrier and the direction of the prevailing wind is acute, the wind will be concentrated in the middle part of the sand dune, and therefore the sand barrier is liable to be destroyed in this area. If the angle is between 90° and 100°, the wind will go along the two sides of the obstruction. The effectiveness of the sand-control of this kind of sand barrier is satisfactory (Fig. 2.8).

The disposing patterns of sand barriers are mainly as follows: linear-shape, parallel lines, trellis (check) shape and fishbone shape. In an area where the direction

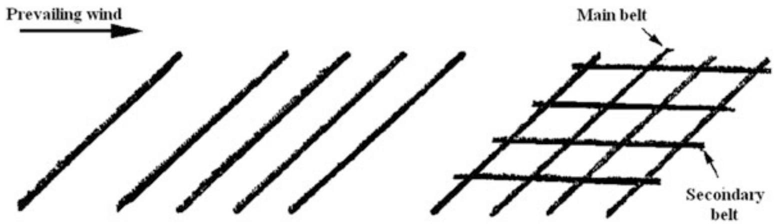


Fig. 2.9 The patterns of some sand barriers

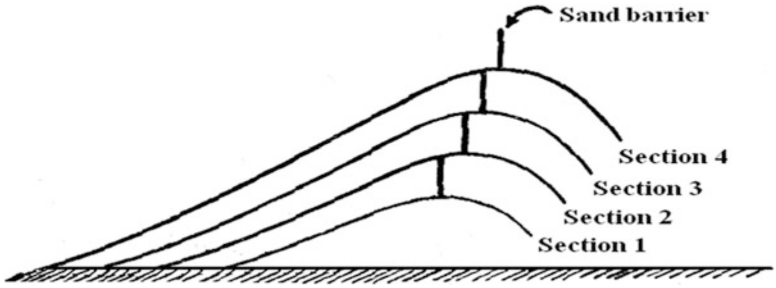


Fig. 2.10 The section of linear-shaped sand barrier

of wind is single, linear-shaped or parallel linear-shaped sand barriers are usually adopted, but in an area where side winds are strong, the check-shaped sand barriers are often used (Fig. 2.9).

Linear-shaped sand barriers are generally established in an area where the threat of sand-driving wind is serious. Its function is to hold back the shifting sand. This kind of sand barrier is called "stopping up the wind gaps" by local people. The linear-shaped sand barriers are often used as high standing sand barriers or hedges. When the dropped sand buries a sand barrier, the barrier should be raised or rebuilt. The height of the sand mound on the leeward side of sand barrier will gradually increase and the dropped sand will form a great sand dune – a great sand-blocking dam-in the end (Fig. 2.10).

Parallel linear-shaped and check-shaped sand barriers are used not only to stabilize the original sand dune on the spot, but also to hold back the passing sand carried by the sand-driving wind. These two kinds of sand barriers are usually adopted to guarantee the survival rate and growth of seedling of sand plants that are planted on the sand dunes.

All of the above patterns of sand barriers are only suitable for areas where the sandy land is gentle and the landforms are simple. For an area where the landforms are varied, other patterns of sand barriers should be set up in the light of the type, run and slopes of the sand dunes.

When sand barriers are set up on crescent (barchans or semi-lunar) dunes, the top of the windward slope of the dune should be left open so as to let the part which is

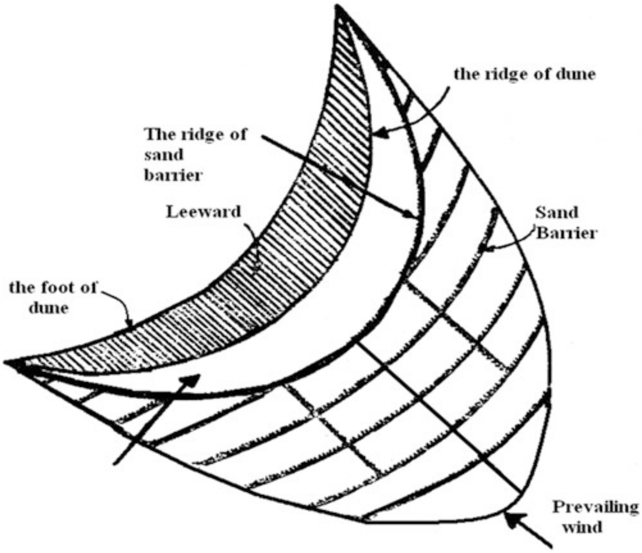


Fig. 2.11 The disposing patterns of sand barrier of the windward slopes of crescent dunes

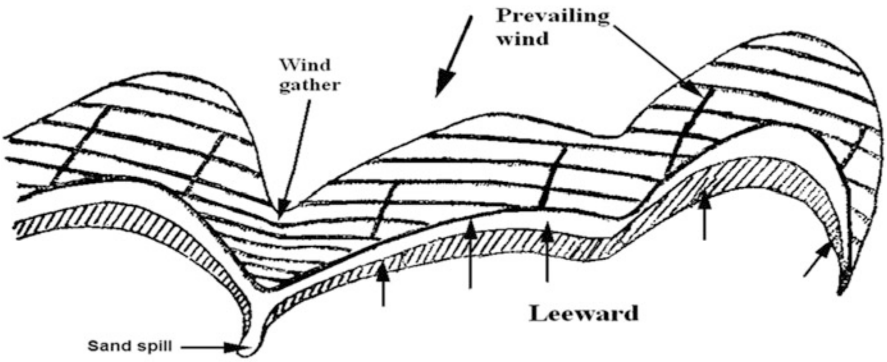


Fig. 2.12 The disposing patterns of sand barriers on the semi-lunar dune chains

not protected by the barrier be moved by the wind. The sand on this part will then fall into the leeward slope of sand dunes (Fig. 2.11).

The patterns of sand barriers on semi-lunar dune chains are more complex (Fig. 2.12).

On the various sections of semi-lunar dune chains, sand barrier can be set up in the same fashion as on individual semi-lunar dunes, but where two dunes link up, the parallel linear-shaped sand barriers should be adopted because this area is a wind-gathering area. The direction of wind here is steady and the sand-driving wind force is strong. If the material of the sand barrier is clay, the distance between two barrier

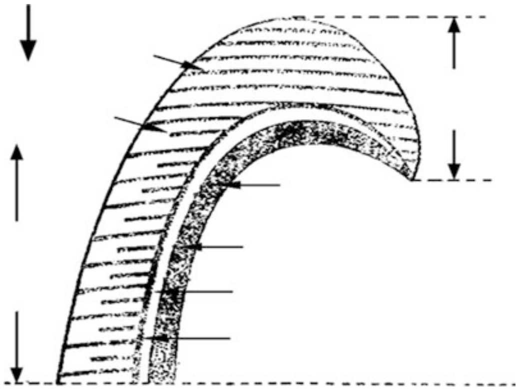


Fig. 2.13 The disposing patterns at the head of longitudinal dunes

lines should be shortened. The undulations on the semi-lunar dunes show that the winds here are various and unsteady. In such circumstances the check-shaped sand barriers should be used. The patterns of sand barriers on longitudinal dunes are illustrated in Fig. 2.13.

The disposal patterns of sand barriers at the head of longitudinal dunes are the same as the patterns on the windward slope of semi-lunar dunes. The patterns on the body of longitudinal dunes are complex. The body of a longitudinal dune can be divided into a windward slope and a leeward slope. The patterns on the windward slope of longitudinal dunes are similar to those on the semi-lunar dunes. A main sand barrier on the ridge of a longitudinal dune, along the run of the dune, should be established first. And then secondary barriers that are vertical to that main sand barrier are set up. In order to eliminate the vortex flow, the run of the secondary barriers should be inclined in the direction of the prevailing wind. To revise the distance between two barrier lines and the run of sand barriers, some short barrier lines among the secondary barriers should be set up. For the longitudinal dunes whose surface is gentle and smooth, fishbone-shaped or double fishbone-shaped sand barriers are usually adopted.

For the complicated irregular sand dunes, the fishbone-shaped sand barriers are usually used by local inhabitants of the sandy area (Fig. 2.14).

Fishbone-shaped sand barriers are composed of a main barrier and many secondary barriers. The latter consist of two kinds. One is a longer barrier from ridge of sand dunes to the foot of the dunes, and the other is a shorter barrier inter spread among the longer ones as needed to adjust the pattern.

4.3.2 Row Spacing and Standard Dimensions of Sand Barriers

The row spacing of high standing sand barriers must be appropriate for the conditions. If it is too wide, the sand barrier is liable to be destroyed by blown sand. Conversely, if the row spacing is too close, man-hours and materials are wasted. From the experiences of local people, the row spacing of sand barriers should be

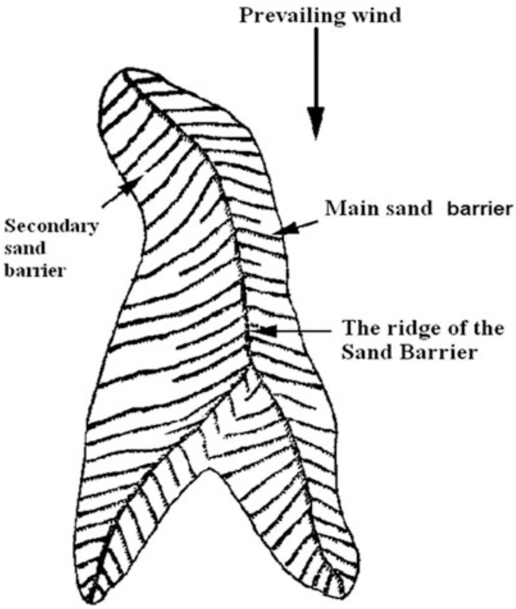


Fig. 2.14 The disposing patterns of sand barrier on the complicated irregular sand dune

smaller in those areas where the wind is strong, and on the top of the dunes. In other areas, the spacing can be increased. In general, the row spacing of sand barriers can be determined on the basis of the following factors: (1) The *height of the sand barrier*: the higher the sand barrier, the wider the row spacing; (2) The *slope of sand surface*: the steeper the slope, the closer the row spacing; (3) The *wind force*: the stronger the wind force, the closer the row spacing; (4) The *part of sand dunes*: the row spacing is closer on the top than that at the foot of the sand dunes; (5) The *structure of the sand barrier*: the denser the structure of the sand barrier, the closer the row spacing.

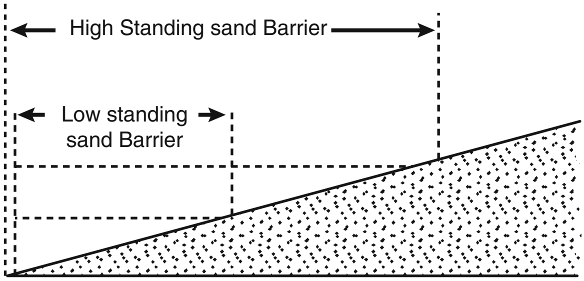
High Standing Sand Barrier

Under normal conditions, on a gentle slope, which is less then 4°, the row spacing of sand barriers should be 10–15 times the height of the sand barrier. Of course, the wind force should be considered in this case. When the sand barriers are set up on the windward slope, the base of the barrier which is located on the upper part of the dunes should be lower than the tip of the next barrier which is situated to the lower part of sand dunes (see Fig. 2.15).

When barriers of a given height are set up on the slope of sand dunes, the row spacing is closer for the steep slope and wider for the gentle slope. The steeper slope of the sand dunes, the closer the row spacing of the barrier (Fig. 2.16).

There is a close relationship between row spacing of sand barriers and the height of sand barriers, as well as the slop of sand dunes (see Table 2.1).

Fig. 2.15 The relationship between the height and the row spacing of the sand barrier



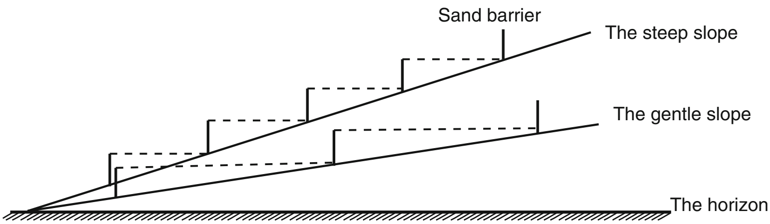


Fig. 2.16 The relationship between the slope of sand and the row spacing of sand barrier

Table 2.1 The ranges of row spacing of straw and branch sand barriers

The general height of the barriers		The row spacing for various slopes (m)		
Types	Height (cm)	5°	5°–10°	10°–15°
Low standing sand barriers	20–40	3–5	2–3	1–2
High standing sand barriers	60–80	7–10	5–7	3–4

The row spacing of clay sand barriers (or other low standing sand barriers with dense structure established for afforestation on the sand dunes) is mainly determined on the basis of the special needs of planting.

The intention of sand barriers that are set up for afforestation is that a depression among the sand barriers will form after several episodes of strong sand-driving wind and the sand will heap up around the barriers simultaneously. If the run of the sand barrier is correct, the depression will quickly become stable.

The depth of the steady depression among the sand barriers is about 1/12 of the row spacing of the sand barriers. And the deepest part is not more than 1/10 of the row spacing. The wider the row spacing, the deeper the depression.

If the height of the sand barriers is less than 1/10 of the row spacing, the sections between the sand barriers will be eroded. On the contrary, if the height of the sand barriers is more than 1/10 of the row spacing of the sand barrier, the sand will heap up in those sections. Therefore the phenomenon of sand-dropping or erosion on the surface of sand dunes which are protected by sand barriers can be determined not only by the row spacing of sand barriers, but also by the height of the sand barriers (Fig. 2.17).

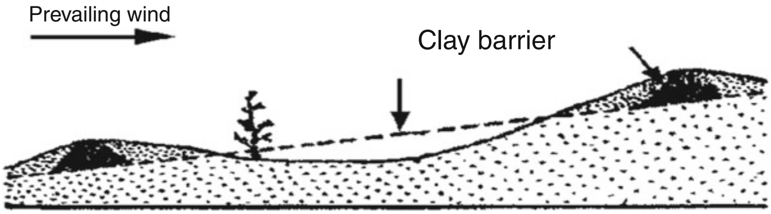


Fig. 2.17 The relationship of the stable surface of sand dune and the concave part around the sand barriers

The row spacing and the height of clay sand barriers should be determined on the basis of the above-mentioned principles.

4.3.3 The Row Spacing of Clay Sand Barriers

From the point of view of sand control, it is inadvisable to adopt too large a row spacing for clay sand barriers. If the row spacing is too large, the sand among the sand barriers will be easily carried away by the wind and a deep depression will form among the sand barriers. From practical experience, the depth of the depression should not be more than 40 cm and the row spacing of sand barriers should be kept under 10 times the above dimension. This means that the row spacing of sand barriers should be kept less than 4 m. Such sand barriers can control sand steadily and effectively. Only for areas where the wind direction is constant and the sand surface is gentle, can a row spacing of 5–6 m or more be used; In general, a row spacing of 2–4 m is usually adopted.

4.3.4 The Size of Narrow Mound Clay Sand Barriers

The proper size of narrow mound clay sand barriers is crucial to afforestation on the sand dunes because it can not only prevent the protected sand being carried away by the wind, but also avoid the sand carried by the wind from heaping up in the protected area. In order to ensure the survival and the growth of seedlings of plants which are sown among the sand barriers, the eroded depressions should be kept at less than 5 cm, and the biggest depth should not exceed 15 cm, because the depth of the dry sand layer on the sand dunes is usually 5–15 cm. Therefore the height of the clay sand barriers can be calculated in the light of the determined row spacing, the general depth (1/12 of the row spacing) of depression among the sand barriers and the biggest depth (1/10 of the row spacing) of the depression. The most common row spacing of clay sand barriers is 3 m. Under such circumstances, the depth of the depression among the sand barriers is about 25 cm and the biggest depth is not more than 30 cm. To maintain an eroded depth of less than 5 cm between the sand barriers, clay sand barriers with a height of around 20 cm and a width at the bottom of about 60 cm are often adopted. With the row spacing being shortened, the size of the clay sand barriers should also be narrowed and cut down, but if the size of the clay sand barrier is too small, the barrier is liable to be destroyed by wind, livestock or people. Under normal conditions, the row spacing and the height of clay sand barriers is 2–4 m and 15–25 cm, respectively. For different row spacing and sizes of clay sand barriers, the amount of earthwork and manpower are also different.

4.4 Installation of Straw Sand Barriers

The best seasons for setting up straw sand barriers are the end of autumn and early winter. Because the sand is moist in these periods, a lot of labor can be saved and the base of the sand barrier firmly established. If sand barriers are set up in the summer or spring, the base of the sand barrier is easily destroyed by the wind because the sand is dry in these seasons, and it is difficult to set up sand barriers on dry sandy land.

4.4.1 Installation of High Standing Sand Barriers

The heights of standing sand barriers that are made of tall and supple stalks (such as reeds and the stalks of *Achnatherum splendens*) should be more than 70–80 cm. The installing techniques of standing sand barriers are as follows: (1) dig the furrows along the designated lines. (2) put the materials-stalks-into the furrow with the tip of the stalks up and the base down. More should be in the furrow than out of the furrow. The barrier must be very dense and leave no spaces in it or it will be liable to be destroyed by wind. (3) fill the furrow with the broken stalks first and then with sand above the broken stalks on both sides of the sand barrier.

In order to make the sand barriers very firm, the filled sand on both sides of the sand barrier should be more than 10 cm above the ground level (see Fig. 2.18).

The density of the materials should be about 0.2–0.4 kg/m but if the material sources are not locally abundant, the cost of establishing the barrier is much higher. Standing stalk sand barriers can break the sand-driving wind no matter whether the wind is strong or weak.

4.4.2 Installation of Low Standing Sand Barriers

The materials for low standing sand barriers are usually as follows: grasses, shrubs, sub shrubs, branches of trees, wheat straw and other crop stalks or straw. The installing techniques can be divided into two kinds according to the different materials used:

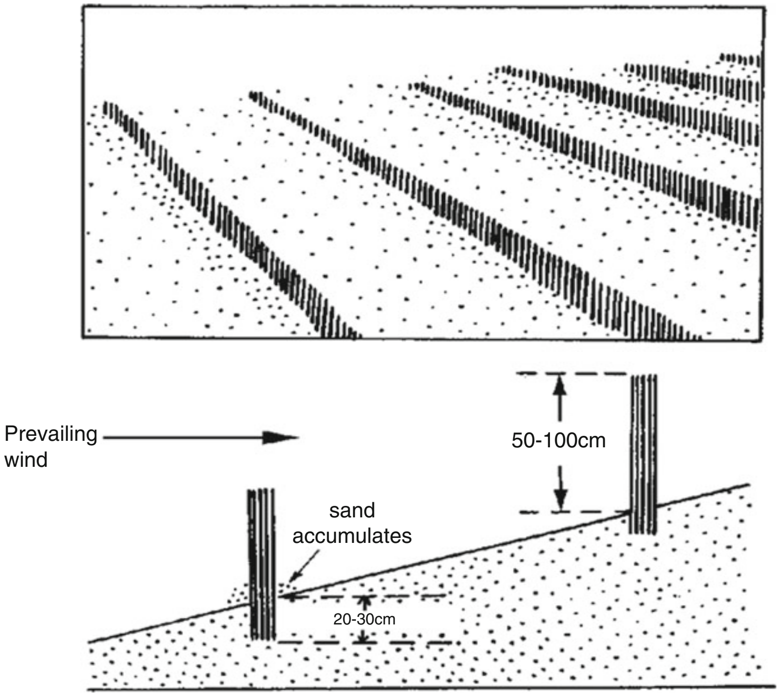


Fig. 2.18 The installing techniques of high standing sand barrier

1. Setting up in the furrow
   The materials used in this method are hard, such as the branches of *Nitraria tangutorum*, *Artemisia ordosica* and *Alhagi sparsifolia*. First, a furrow, width 15 cm, depth 20 cm should be dug. Second the materials are put into the furrow with the roots up and the tips down and the sheaves or branches are overlapped (see Fig. 2.17). It is better to keep the degree of density of the sand barriers at 20–30 %. The height of the low standing sand barriers is usually around 30 cm. Finally, the furrow is filled with sand and then tamped firm. Sometimes, in order to avoid the base of the sand barriers being destroyed by the wind, some broken straws are firstly filled into the furrow on the windward side of the sand barriers and then covered with sand.
2. Setting up by pushing down the straws
   For some soft straws, such as wheat straws, it is not necessary to dig a furrow when the sand barriers are set up. The steps for installation of such sand barriers are as follows (see Fig. 2.19):

   (1) lay the straws along the designated lines evenly and make the run of the straws vertical to the lines; (2) press the middle of the straws into the sand to a depth of around 10–15 cm with a blunt spade. Thus the two ends of the straws

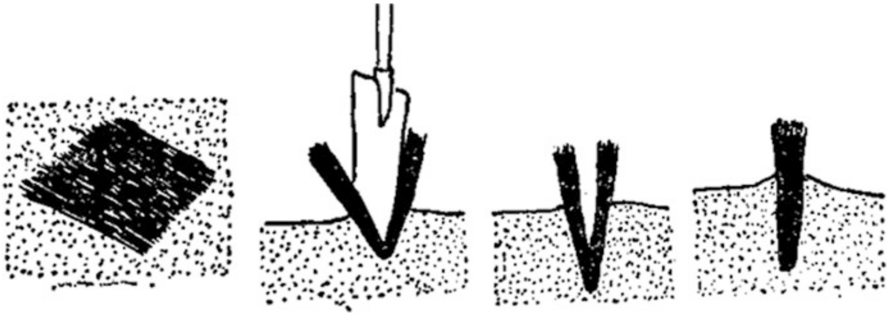


Fig. 2.19 The installer's method of soft spread sand barriers

will rise up; (3) close the two separate sides of the straws into one and tramp the base of the sand barriers on both sides with feet. The advantages of this method are that it is fast and saving of manpower.

4.4.3 Installation of Concealed Sand Barriers

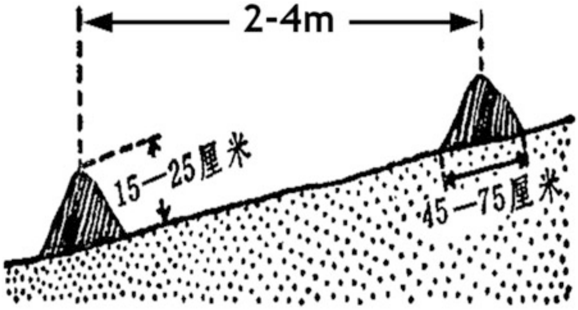
The materials for concealed sand barriers are usually wheat straw, reeds or other grasses. The installing method is as follows: (1) cut the straws or grasses into 20–25 cm lengths and then bundle up the cut straws or grasses to a diameter of 5 cm; (2) dig the furrows on the sandy land to a depth which is the same as the length of the bundle; (3) stand the bundles into the furrow and then fill the furrow with sand and tramp it firm. The tips of the bundles of straws or grasses are at ground level. Such sand barriers cannot break the sand-driving wind above the ground. But they can control the moving of the sand ripples on the surface of sand dunes. When the concealed sand barriers are set up, the existing landforms can be kept although the sand is still moving. This phenomenon is advantageous to afforestation on the moving dunes. The patterns of this kind of sand barrier are usually parallel linear-shaped with row spacing of around 2 m, or check-shaped with a size of 2×3 m. For this kind of sand barrier, there is another installing method; this is digging a furrow to a depth of 15–20 cm and laying the straws or grasses into the furrow and then filling the furrow with sand (Fig. 2.20). This method can save man-hours, but its efficacy at sand-control is not very satisfactory. This method is usually adopted when the materials are broken straws or grasses.

4.4.4 Installation of Clay Sand Barrier

The clay sand barrier belongs to the low standing type of sand barrier with windproof structure. In many sandy areas, the clay sand barrier is set up first before the sand-adapted species, such *as Haloxylon ammodendron*, are planted

Fig. 2.20 Installation of materials in furrows

Fig. 2.21 The section of clay sand barrier. Major barriers are placed 2–4 m apart with a base of 15–25 cm in the lower slopes and 45–75 cm in the upper parts



on the moving dunes. The effectiveness of the clay sand barrier for sand-control near farmlands and irrigation canals is also very satisfactory. Clay sand barriers are widely accepted by the local people living in the sandy areas. In general, the clay sand barrier is set up at the lower part (approximate 2/3 of the slope) of the windward slope of sand dunes. Before setting up, the lines should be drawn on the basis of the direction of the prevailing wind, the shapes of the sand dunes, section of the dunes, size and row spacing of the sand barriers and so on. The narrow mounds, along the lines, are piled with clay that is taken from lowland between the sand dunes. A row spacing of 3 m and a mound of 20 cm in height are usually used (Fig. 2.21).

For the sand barriers that are established on the upper part of the slope and on the steep slopes of sand dunes, the row spacing should be shortened and the height should be raised. For areas where the ground is gentle and the sand dunes are steady, a sand barrier of smaller size can be used. The width of the mound should be kept even, or it will be destroyed by wind at the narrowed part. In order to maintain an uneven surface, lumps of the clay should be used, but very big lumps of clay should not be used because they will probably cause wind-erosion around them. Clay barriers should be examined after several exposures to strong winds. The following aspects should be examined: (1) whether the run of the barrier is correct or not; (2) whether the depressions among the sand barriers are eroded or not; (3) the angles between the run of sand ripples and the run of the sand barriers; (4) the angles between the sand plaits and the run of the clay sand barriers; (5) whether any part of the sand barrier has been destroyed.

If the run of the sand barriers is wrong, secondary sand barriers should be set up so that erosion can be controlled. If some parts of the sand barriers have been destroyed, they must be repaired immediately.

Initially, clay sand barriers can improve the moisture conditions of sandy land because the depressions among the sand barriers can collect the run-off of any rain. According to observation: with a precipitation of 25 cm in 4 days, the water permeates to depths of between 28.5 and 35.6 cm on the sand dunes protected by the clay sand barriers and to a depth of only 18.5–23 cm on bare sand dunes. The moisture contents in the depth of 0–15 cm are that, 13.35 mm for the dunes protected by high standing sand barriers, under 10 mm for the low standing sand barriers and 16–16.65 mm for the clay sand barriers. The moisture status of the sand protected by the clay sand barriers is greatly improved. The depths of the dry sand layers of sand dunes protected by the clay sand barrier and by the straw sand barrier are 8–10 and 18–20 cm, respectively, therefore for the sake of afforestation, the clay sand barrier is better than others.

However, at a later period after installation of the clay sand barrier, thin crusts will form on the sand surface because of the washing of the rainwater. This can prevent the rainfall seeping into the sand dunes. In this case, the moisture conditions of the sand dunes will have harmful effects on afforestation. Therefore afforestation should be undertaken immediately in the spring following the setting up of the barrier.

At 20 cm above the ground, the clay sand barrier can reduce the wind velocity by 27–33 %, the high standing straw sand barrier by 42 % and the low standing straw barrier by 8–17 %. At 2 m above the ground, the clay sand barrier can reduce the wind velocity by 40 % or more, and the straw sand barrier can reduce the wind velocity by 10–40 %. Therefore, in respect to the function of protecting seedlings, the clay sand barrier is better than other barriers. The cost of the clay barrier is the lowest among the various sand barriers because it only consumes manpower. The materials -the clay- are located on the low land which is just on the foot of the sand dunes. Therefore the clay sand barrier can not only reduce the cost, but also save a lot of other materials, such as straws, stalks, and branches, etc. So in many areas where a clay source is available and the straws or branches are in short supply, the clay sand barrier is the best choice.

The cost of the man-power for the clay sand barrier is around 150 man days/ha, but for covering a sand dune with earth, this cost is about 1,500 man days/ha, The cost for labor of the clay sand barrier ,the straw sand barrier and the branch sand barrier are about RMB 0.60, 1.05 and 1.05 Yuan/m, respectively. So the cost of the clay sand barrier is the lowest one. In general, the service life of the clay sand barrier, if it has been set up correctly, is around 4–5 years. The plants such as *Haloxylon persicum*, which are planted in the sand barriers, can exercise a function of sand-control very effectively within 2–3 years of planting. At this point plants can replace the clay sand barrier to control moving sand.

5 Implementation of Mechanical Measures in China – Proven Practices

In the arid part of northwest China, transport routes links are very important for the economic development of the region and to the welfare of the people. Hence, the total length of the railway lines crossing the sandy area are about 1,200 km, with wind-sand catastrophe taking place in an area of about 200 km wide and 1,000 km long, these include railway lines of Baotou-Lanzhou, Jining-Erlianhaote, Gantang-Wuwei, Lanzhou-Wulumqi, Baotou-Shengfu and there are other lines which are under construction. Effective prevention and control measures have been applied to about 50 % of the rail lines in the desert region (Chen Guangting 2005). There are lots of major highway lines passing through the arid areas and these include the highways of Xilinhaote-Zhangjiakou in Inner Mongolia that cross the sandy area of Hunsantake, Baotou-Yulin crossing the Kubuqi and Maowusu desert and the highway of Taklamakan desert. The last mentioned has been a great success but involved many challenges (Box 2.1).

Box 2.1: The Miracle of the Takliman Desert Highway

Taklimakan desert is the largest in China and the second most active desert in the world. Eighty-five percent of the area is drifting dunes, having the strongest fluxion among the entire deserts in the world. Ninety-two percent of these sand dune lines cross the mobile sand area, and are composed of all kinds of mobile dunes with different shapes and heights. The mechanical measures of prevention, stabilization, transportation, conduction, and control are all used synthetically. Building a highway in this desert marked the study of measures on controlling sands. The designers took part in the design of the road beds, especially on the wind gap or sand platforms, designing sections for transporting sands, and cleared the barrier on both sides of the lines allowing the sand flows to cross the roads and with no depositing on the road beds. In the section where the wind is uni-directional, dividing fence into sections with tangle angles creates feather rows to conduct sands. However, most of the prevention systems are sand-fences and straw checkerboards along the desert highway in Taklimakan desert. The materials used to weave fences are taken from reeds and in order to construct fences quickly, nylon webs had superseded most fence material. The widths of shelterbelts are laid out according to the positions of the aeolian sand landforms and are adapted with flexibility.

The prevention method together with the mechanical measures along the desert highway in Taklimakan desert assure that the highway remains open, accelerating oil exploration and exploitation and development in the

(continued)

Box 2.1 (continued)
hinterland. The desert highway reclamation program received a nomination for the tenth national achievements in science and technology in 1995, and received the National first prize for progress in science and technology in 1996.

The Shapotou Research station on the Yellow River (Box 2.2) developed many of the techniques that were described above and which have been applied in the protection of trans-desert transport routes. The construction of the prevention systems along the Baotou-Lanzhou railway line was awarded the National Prize on progress in Science and Technology in 1986, and this was the initial desert railway line crossing the southeast edge of the Tenggeli desert. In this area, grid dunes dominate among the types of aeolian sand landforms with relative heights of 15–20 m, and an annual average rainfall of about 185 mm, and a deep ground water level that cannot be exploited by vegetation.

Box 2.2: The Shapotou Experimental Station, Ningxia, China

Shapotou Experimental Station was established in 1956, to find ways of stabilizing mobile sand dunes of the Tengger Desert (Zhu and Liu 1989). In 1956, the Batou to Lanzhou railway was constructed through 40 km of the southern Tenggelli Desert (Plate 2). Therefore methods were required to reduce sand encroachment on the rail track. Besides planting trees as wind breaks, a procedure for establishing an artificial ecosystem on mobile dunes was derived. The process converts areas with shifting sands with less than 5 % vegetative cover to areas of fixed dunes with 30–50 % cover. Initially, a sand barrier is established, encouraging aeolian deposition. Behind the sand barrier, straw checkerboards (Fig. 2.22) are constructed which increase aerodynamic roughness, thereby decreasing wind velocity and stabilizing the surface.

The prevention systems developed at Shapotou have two essentials which are *fixation* and *prevention*. These were divided into four belts by disposition; Firstly, the belt of preventing sands on the edge, using different material, with a height about 1 m, equal to sand-fences preventing sand shifting, secondly, the belt of fixing sands with no irrigation. Straw checkerboards (1 m $\times$ 1 m) are the main parts of the prevention systems mixed with the shrubs and herbs, thirdly, the belt of trees and shrubs with irrigation and fourthly, the belt of transporting sands with pebble platforms.

The lengths of the integrated fundamentals belts are about 9 km including the section of the second and fourth belt and the rest are composed of the belts of fixation and transportation.

Fig. 2.22 A view of part of the Shapotou Desert Research Station showing the system of checkerboards made with straw to increase surface roughness and reduce sand movement

Many railways pass through the Gobi area which as a result of strong winds and scarcity of sands is saturated with sand flows, 60 % of the Lanzhou-Xingjiang lines cross the Gobi area and the Yumen sections (Hesan Lake-Wangdong, Sanshilijing-Gongchan River and Junken-Erdaogou) lie north of the Qilian Mountain. The prevention systems on this railway obtained the first National Prize on Progress in Science and Technology in 1954.

In response to strong winds, insufficiency of sand resources and the erosion abilities of sand flows, major measures were adapted which included reducing the wind velocity and shut off sandy resources and combination of prevention and protection. At the edge of the railway lines there are higher sand barriers, which include shrub branches and other materials which form a fence height of about 1.5 m. After 20 years of construction and study, by the end of 1994, on both sides of railway lines Junken-Erdaogou, Sanshilijing-Gongchanghe River, 96 km of shelterbelts of prevention have been established. The work has continued and China's proven technologies have been adopted elsewhere (Yang et al. 2005, 2011).

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Chapter 3
Successful Biological Methods for Combating Desertification at Degraded Areas of China

G. Ali Heshmati

Synopsis This chapter explores the use of biological (plant-based) techniques for stabilizing and revegetating sandy lands. In some cases revegetation is only possible after the moving sands are fixed (as explained in Chap. 2) in other cases revegetation with sand-loving species can be successful using either vegetative materials or by direct seeding. Different methods would be suitable for protecting various sites. Some useful models, developed over years of trial and error, are introduced and their features are explained.

Key points

- There are more than 750 counties in 13 provinces and autonomous regions which are facing serious problems of desertification. These areas, that represent approximately, 30 % of China's land area are mainly distributed in arid, semi-arid and dry sub-humid areas in northern China, especially northwest China.
- Biological methods are the ultimate way to rehabilitate sandy land and a fundamental approach to the development and proper utilization of desert. There are 12 deserts in two physiographical situations (either hilly or low-land situations) where some successful biological methods for combating desertification have been documented. These methods were used on the basis of rational land use and the best plant species which are suitable for these harsh conditions.
- The land use categories that are suffering most from desertification are: agricultural areas, highways, railways, roads, cities, industrial sites and mining areas. The important plant species were used for combating desertification are: *Hedysarum laeve, H. scoparium, Amorpha fruticosa, Lespedeza bicolor, Caragana microphylla, C. korshinskii, Artemisia halodendron, A. phaerocephala,*

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Astragalus adsurgens, Ulmus pumila, Hippophae rhamnoides. Haloxylon ammodendron, Calligonum mongolicum.

- Transplanted seedlings, direct sowing, use of cuttings, and air seeding techniques were used for greening areas degraded by wind and water erosion. Different models have been applied for protecting agricultural areas, Cities, transportation routes (highways, railways and roads) industrial infrastructure or mining sites and water storage reservoirs. Some successful models which have been employed are: Shelter forest system in oases, shelter system for sand fixation at agricultural areas, transportation, industrial sites or mines and reservoirs.

Keywords China • Desert • Biological methods • Plant species • Aerial seeding • Transport corridors • Land use • Shelter forest • Mining sites • Plastic mulching • Nursery

1 Introduction

The Chinese people are unremitting in their efforts to struggle against the adverse effects of desert encroachment and desertification. Some available measures to fix shifting sands in the different regions have been created by Chinese scientists through the successive implementation in such major ecology restoration projects as the Three North Regions Shelterbelt Construction Project, including the "Great Green Wall" project involving integrated shelterbelts extending over thousands of km (Fig. 3.1) and the National Action Program to Combat Desertification.

Effective progress in the aspects of re-vegetation, rangeland improvement and soil and water conservation have been made in the affected areas. Some acceptable and practical techniques, successful demonstrations and rich experiences as well as extension service models to combat desertification and manage dry lands have been developed at community, local and national levels. For instance, the techniques of dune fixation and sand stabilization with biological and mechanical measures along railways, highway and at mining facilities have been created. The techniques of aerial-seeding of bushes and grasses to re-vegetate shifting sand lands were used. The technical measure of rice cultivation with under-soil plastic mulching in dune areas and countermeasures to implement integrated management of watershed were also applied. The traditional skill of rational rotation grazing system with determination of rangeland quality and carrying capacity were employed. The approaches to develop fodder farms and high efficiency grazing land and raise public awareness of the benefits of feeding livestock in pens/sheds and the development of eco-farms as a means of improving vegetation cover. According to the demand of the development of the national economy of China, appropriate balance should be kept among agriculture, forestry and pasture. The arrangement of the tree plantation generally does not affect grass and shrub vegetation on rangelands, so they should arrange afforestation according to the technical requirement, while minimizing impact on the croplands and rangelands.

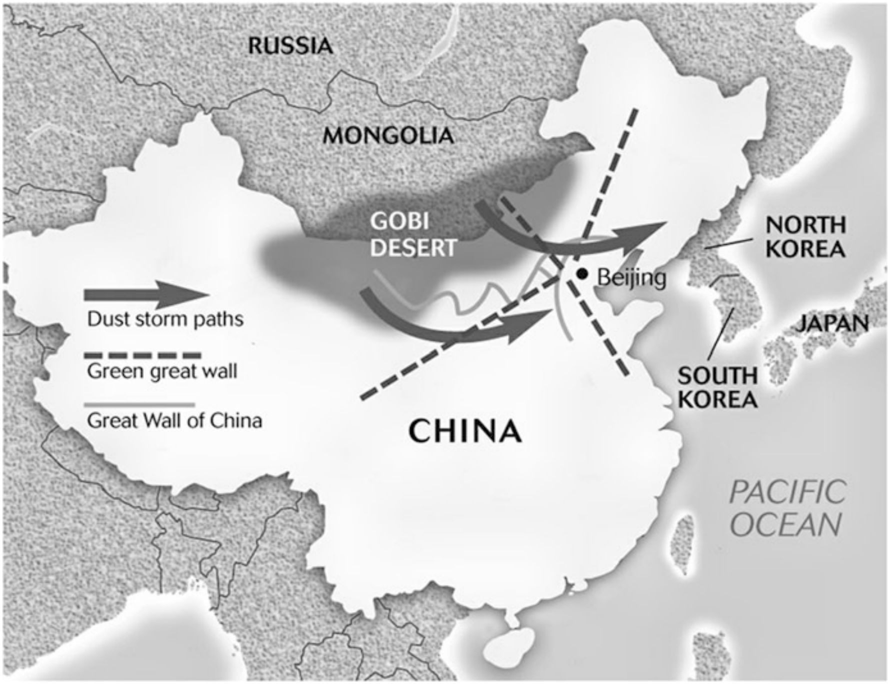

Fig. 3.1 "The Great Green Wall" extends for hundreds of km in northern China to reduce the impact of dust and sandstorms that originate in Mongolia and Inner Mongolia

Biological methods are the ultimate way for drift sand stabilization and a fundamental approach to the development and proper utilization of desert (Yaolin and Jihe 2005). The measures used to fix sands in China can be classified into two types: One is to protect the extant vegetation on the sand dunes or, where such vegetation has deteriorated, to plant trees, shrubs and grasses. This type is called a biological methods or plant measure for desert control. Another approach involves the mechanical measures (see Chap. 2).

2 Raising Seedlings of Desert-Adapted Plants

The nursery garden is the base for seedling production. Seedling raising, which is strongly limited by seasons, need to be done intensively, that means to raise high-quality seedlings with the lowest cost and in the shortest time. The yield, quality and cost of seedlings are all strongly affected by natural conditions of the area where the nursery garden is located. So, before establishing a nursery garden, especially a permanent garden with large area, the conditions in the garden, as well as the types and the characteristics of the seedlings need to be surveyed and analyzed. And then a conclusion whether it is suitable to be established as a garden can be made. Therefore, the establishment of a nursery garden is a work of great importance.

2.1 Types of Nursery Gardens

The general name is nursery garden but they can be classified according to the quantity and usage of the seedlings to be planted in the garden. Nursery gardens can be used for production of (i) sand-fixation seedlings, (ii) tree seedlings for timber (lumber), (iii) windbreak seedlings, (iv) greening seedlings, (v) orchard seedlings, (vi) special economic seedlings and (vii) seedlings for trials. Based on the service lives of different nursery gardens, the gardens can be divided into two types: regular ones and temporary ones.

2.1.1 Land Preparation

Land preparation is an important technical step during the whole process of seedling production. Its purpose is to change the physical situation of soils, to increase soil fertility so as to meet the demands for water, temperature, heat and ventilation to foster seedling growth. There are four steps for land preparation:

1. Plowing (shallow or deep),
2. Break up clods,
3. Soil compacting,
4. Harrowing,
5. Inter-cultivation.

2.1.2 Fertilizer Application

The purpose of applying fertilizer is to improve soil fertility, change the physical characteristics of soil, (with soil ameliorants such as gypsum) and promote the microbiological activities and the decomposition of organic matter. The types of fertilizers are: Organic fertilizer, Chemical fertilizer and inoculants such as rhizobia and mycorrhiza. The quantity, method and time of fertilizer application are important for nursery garden.

2.1.3 Soil Fumigation

Its purpose is to kill virus and pest and diseases in the soil. Treatments involve heating soil to a high temperature. Application of pharmaceutical products are generally adopted. The pharmaceutical product treatment is usually adopted to raise seedlings in desert areas.

Table 3.1 Sowing rate of several main sand-holding species

Species	Seed quantity per mu (kg[a])	Species	Seed quantity per mu (kg)[a]
Haloxylon ammodendron	1.5–2	*Tamarix* spp.	0.5–0.7
Elaeagnus angustifolia	20–30	*Calligonum* spp.	10–12
Hedysarum scoparium	10–12	*Nitraria tangutorum*	10–12
Caragana korshinskii	13–15	*Artemisia arenaria*	0.5–1

[a]*Note: 15 mu = 1 ha*

- Formalin: 12–20 days before sowing, spray the soil with Formalin solution (50 ml Formalin + 6–12 l water/m^2), then cover it with plastic film. One week before sowing, uncover the film. The sowing can be done when there is no chemical smell.
- Ferrous sulfate: applied in the form of water solution with the concentration of 2–3 %, 9 l/m^2.
- Dikesong: The quantity and method of applying it are same as above.
- Also important treatments for different seeds, sowing period, sowing rate and sowing methods are necessary.

The sowing rate for different plant species with seed quantity are recommended by the scientists for planting of sandy lands of China (Table 3.1). The sowing rate depends on whether the seed is planted in rows or is broadcast (hand spread) or used in spot treatments.

2.1.4 Management During Seedling Stage

The management during the seedling stage, including soil management (fertilizer application, irrigation, inter-cultivation and weeding), management and protection of seedlings (thinning, shading, control pests and diseases and winter protection, etc.), will begin after emergence and continue until transplanting. Irrigation, weeding and thinning are necessary activities during the seedling stage.

- **Species selection** Natural conditions in various desert areas are quite different. So, the selection of the species is the key of the successful artificial afforestation. If the suitable species were not selected, not only will afforestation fail but there would be waste of labor, material and money; also the potential of the land will not realized due to the lack of trees on it. When selecting suitable species, the following should be taken into consideration:

1. Select local sand fixing species which grow well;
2. Select the species with high economic value e.g. for construction materials, or have fruits or nuts;

There are four main factors effecting the selection of desert plants: zonal, temperature, ecological series and Sand dune sectors. There are a series of plant species which are suitable for different desert types (Table 3.2).

Table 3.2 Suitable plant species for different sandy land types

	Land type	Suitable species
1	Sandy land (flat)	*Populus euphratica, Populus alba var pyramidalis, Populus gansuensis, Reaumuria soongorica, Elaeagnus angustifolia, Caragana korshinskii, Hedysarum scoparium, Haloxylon ammodendron, Calligonum* spp, *Tamarix* spp, *Artemisia arenaria, Zygophyllum xanthoxylum* and *Atraphaxis bracteatea*
2	Sand dunes	*Haloxylon Ammodendron, Tamarix ramosisima, Hedysarum scoparium, Caragana korshinskii, Calligonum arborescens, C. caputmedusae* and *C. mongolicum*
3	Arid area	*Haloxylon Ammodendron, Hedysarum scoparium, Caragana korshinskii*
4	Semi arid area	*Salix matsudana, Populus canadensis, P.simonii, P.nigra var.italica, P. alba var.pyramidalis* and *P.nigra var.thevestina*

3 Land Preparation and Planting

3.1 Natural Conditions in Desert Area

Strong wind, dry climate, rare rainfall events and poor soil are the natural conditions in sandy lands affected by wind and the landform in desert area is rather complex. The site conditions in different sand landforms and in different parts of sand dunes are quite different, which will affect sand fixation and afforestation. The preparation for planting on such areas depends on natural conditions and afforestation season.

3.2 Transplanting

There are several aspects that would be useful for ensuring successful transplanting of seedlings in sandy land. These are:

- Seedling quality (vigor, disease free)
- Seedling protection (from wind abrasion, rodent and insect attack)
- Preparation of planting hole.
- Planting distance (spacing).
- Rehydration of seedlings before planting;
- Planting (depth, soil compaction)

- **Direct seeding**
  This is widely used on flat terrain and here it is important to adhere to the recommended sowing rates (Table 3.2). Seed quality (purity and viability) is important. Some seeds benefit from pre-sowing treatment to break dormancy or increase seed permeability. These pre-treatments are species-specific.

- **Air Seeding:**
  Aerial seeding is a mechanized afforestation method that plants seeds that are spread by plane in a suitable space and time to develop the vegetation so as to fix the shifting sands on a large scale. Aerial sowing has achieved success on Mu Us Sandy lands in Inner Mongolia. The vegetation coverage reached 50–60 % after 4–5 years after sowing. This is of important practical significance to improve the sand control work in the semiarid area of China.

  The advantages of air seeding for afforestation

- Rapid afforestation
- Plane can fly into the remote sand regions to work
- The cost is relatively low

  The selection of plant species

(a) In the desert steppe area
Hedysarum laeve, Amorpha fruticosa, Lespedeza bicolor, Caragana microphylla, Artemisia halodendron, Astragalus adsurgens, Ulmus pumila.
(b) In the steppe and desertfied steppe areas
Hedysarum laeve, Hedysarum scoparium, Artemisia sphaerocephala, Astragalus adsurgens, Caragana korshinskii, Hippophae rhamnoides.
(c) In the arid areas
Haloxylon ammodendron,Calligonum mongolicum, Hedysarum scoparium, Artemisia sphaerocephala.

  The calculation of air-seeding seed rate

(a) The principles of determining rational seed rate are firstly, the seed rate per unit area of the air seeding for afforestation should be determined by the survival plant density in the air-seeding regions in the first year and next year. Secondly, the determination of the seed rate should consider the sand fixing efficiency. Thirdly, the inevitable losses of seeds and seedlings by the rodents, insects, birds and other animals should be taken into consideration.
(b) The empirical formula of the seed rate of the air seeding for afforestation

$$\mathbf{N = n \times g/(1 \times 10^{6\times p}{}_{1\times p2\times p3\times p4})}$$

where:

N is the seed rate (kg/ha) of the air seeding for afforestation,
n is the planned survival seedlings numbers per hectare,
g is the weight of a thousand seeds,
p1 is the purity rate of seeds (%),
p2 is the germination percentage of seeds (%),
p3 is the residual rate of seeds after losses to rodents and insects (%) and
p4 is the survival rate of seedlings in the first year (%).

4 Successful Biological Techniques for Protecting Different Sites

Biological methods are the ultimate way for drift sand stabilization and a fundamental approach to the development and proper utilization of sandy land (Yaolin and Jihe 2005). The measures used to fix sands in China can be classified into two types: One is to protect the existing vegetation on the sand or to plant trees, shrubs and grasses where such vegetation has deteriorated or is absent. Biological methods may or may not be used in conjunction with mechanical measures (Chap. 2). Different methods would be suitable for the various conditions and also for different purposes e.g. protection of infrastructure.

4.1 General Biological Characteristics of Plant Species

Artificial plantations of trees, shrubs and grass are the most effective measures to stabilize mobile dunes and fix shifting sands in arid, semi-arid regions for protecting village and agricultural properties. The methods used in plantation for fixing sands are:

– Plantations of trees, shrubs and grasses in the inter-dune and low-lying lands (Fig. 3.2) Shrubs that have a high resistance to wind erosion are planted on the front or middle part of the windward slopes of dunes (Fig. 3.3)
– Cuttings of species that are drought-resistant in sandy soil, such *Salix* spp., *Artemisia* spp., *Calligonum* spp. are planted in the leeward slopes of sand dunes to fix the sand surface of dunes. This plantation is characterized by non-irrigation, quick growth with production of fodder for livestock and fuel wood (Yang et al. 2005).
– Cuttings of species that are drought-resistant in sandy soil, such *Salix* spp., *Artemisia* spp., *Calligonum* spp. are planted in the leeward slopes of sand dunes to fix the sand surface of dunes. This plantation is characterized by non-irrigation, quick growth with production of fodder for livestock and fuel wood (Yang et al. 2005).

4.1.1 Selection of Sand Binder Species

The region is characterized by a dry climate, strong wind-drift sands, and acute changes in temperature, aridity and infertility of soil. Since 1956, scores of species of trees, shrubs and semi-shrubs have been experimentally introduced and planted on barchan dunes at several sites. The species include: *Pinus tabuleaformis, Pinus sylvestris var. mongolica, Ulmus pumil* and *Robinia pseudoacacia*. These species withered, but some of *Populus simmonii, Populus nigra var. thevestina* have been tested and survived on the leeward slope. But they, even the native species

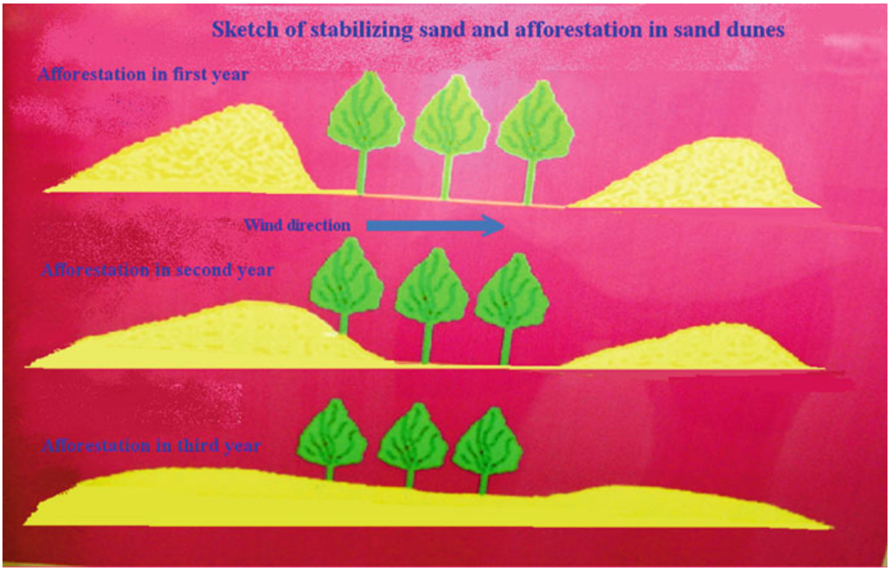

Fig. 3.2 Planting trees in the swales where soil water relations are better is a good way to flatten dunes over a period of several years as sand is transported downwind

like *Elaeagnus angustifolia*, which is drought tolerant, survives as dwarf shrubs. Some trees species like *Ammopiptanthus mongolicus* and shrub, semi-shrubs like, *Amorpha fruticosa, Artemisia halodendron* have been buried by shifting sands or survived with poor growth.

It can be concluded from long-term experiments that the choice of good or pioneer species for binding sands depends on the following criteria:

- Tolerant to hot temperature, aridity and infertility of soil.
- Fast growing, strong germination and ability to survive burying by sand.
- Well-developed root system and potential capability of the horizontal lateral roots to fix dunes and to hold moisture in sands.
- Easy to establish and self-reproducing.

The following species have been selected as the pioneer species from long-term experiments since the 1950s: *Hedysarum scoparium, H. fraticosum, Caragana microphylla, Calligonum arborescens, C. caput-medusae, Atriphaxis bracteata, A. pungens, Salix flavida, Artemisia ordosica,* and *A. sphaerocephala*.

4.1.2 Arrangement, Density and Spacing

Attention should be paid to the suitable arrangement and suitable density, which are essential to the survivorship and vigor of the selected pioneer plants. The plant

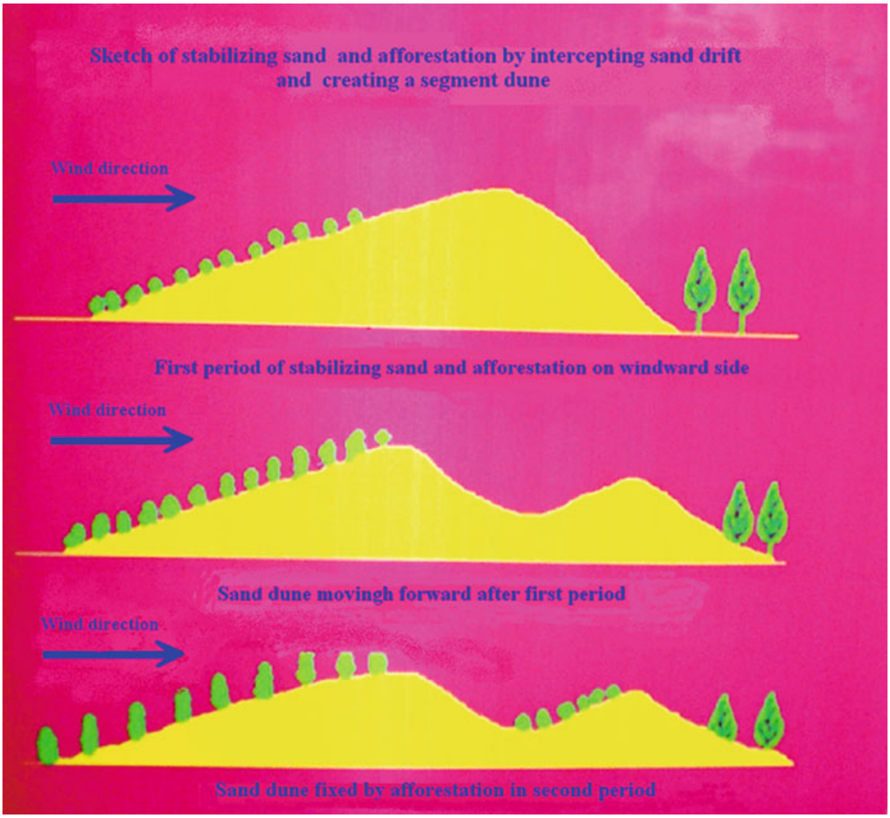

Fig. 3.3 Shrubs that have a high resistance to wind erosion are planted on the front or middle part of the windward slopes of dunes and trees such as *Populus* can be planted on the downwind side

species with different growth forms demonstrate different biological features and different effectiveness to fix sand. The right choice of proper arrangement should be done in light of the specific local site condition when establishing sand breaks, so that all species of the plantation can bring about their desired effect. No single species can play a good role in sand fixing by itself but may be good in combination with others. Other practical considerations go against mono-specific plantations e.g. susceptibility to disease and insects.

Annual and biennial plants are short-lived and only play a limited role in the sand-fixing process. Perennial herbs grow well in the wet years. They have shallow root systems and can obtain moisture at the upper layer of the sand land. So when trees or shrubs are planted, a certain number of perennial herbs should be inter-planted in the same site. By doing so, the competition of moisture and organic matter in the sandy lands can be minimized and vegetation coverage increased. Consequently, the sand-fixing process can be accelerated.

4.1.3 Suitable Physiographical Sites for Plant Species

The different site conditions of various parts of mobile barchan dunes impact the growth of the sand binder species. Wind erosion and burial by sand are the two key factors to limit the survival and growth of plants. The sand layers at the windward slope (eroded part) are more solid and unfit to the development of root systems. The sand layers at the leeward slope (sand burying part) are loose and fit to the growth of the roots. Different species have their own respective properties, such as *Salix flavida*, *Calligonum arborenscens, Atriphaxis bracteata*, and *Artemisia sphaerocephala* are adaptable to loose sand and to burying. Other plants like *Caragana korshinskii*, *Hedysarum scoparium* and *Artemisia ordosica* are fit for inter-plantation on the windward (solid) part (Yang et al. 2005). These scientists suggested the following important points for planting species which are suitable at different physiographical sites.

According to the principle of "appropriate varieties for suitable sites", each of the different species of sand fixing plants should be planted at the most suitable part of the dunes as follows:

- Windward slope: this is the wind eroded part, even if straw grid sand barriers (see Fig. 2.21 in Chap. 2) are built, there is still wind erosion. Its sand layer is more solid so suitable plants include, *Hedysarum scoparium*, *Caragana korshinskii*, *Caragana microphylla* and *Artemisia ordosica*.
- Top of the sand dune: this is the crisscross part of sand burying and wind erosion, the sand layer is looser and suits plants like *Artemisia sphaerocephala*, *Calligonum* spp. and *Atriphaxis bracteata*.
- Leeward slope: this is a sand piling part. Though its sand layer is looser, the sand layer is dry and deep and transplanting can be arranged only after rain. The species of *Salix flavida*, *Calligonum* spp. and *Atriphaxis bracteata* are appropriate plants. Species like *Artemisia ordosica* and *Artemisia sphaerocephala* can be directly seeded during rainy seasons.
- Foot of leeward slope: this is the sand burying part, where those sand resistant plants such as *Salix flavida*, *Calligonum* spp. are suitable.

Proper management is also needed for survival of the sand-fixing plants. A poor planting arrangement may cause an unfavorable impact to the growth and survivorship of the plants. In locations where sand burying is less of a problem it is unnecessary to adopt the mixing arrangement, where the area of windward slope covers over 80 % of the total sand dune, and arrangements of mixed plantation are more suitable than that of mono-species. At Shapotou Station in Ningxia, experiments show that the most acceptable and practical arrangement is the mixture of shrubs with semi-shrubs, namely, the mixed density of *Caragana korshinskii* or *C. microphylla* with *Artemisia ordosica* or the mixture of *Hedysarum scoparium* with *Artemisia ordosica*. The concentrated layer of the root systems of *Artemisia ordosica* are distributed at the depth of 20 cm, that of *Hedysarum scoparium* is mainly at a depth from 20 to 80 cm and that of *Caragana korshinskii* is at 40–90 cm deep. Such plantation mixture with root systems at different depths allows moisture and organic matter in the rooted layers to be fully used. Maximum above -ground biomass can be achieved.

Optimum plantation density is also an important factor guaranteeing the survival of plants used for revegetation of shifting sands. Research at Shapotou (see Chap. 2) compared survival of plants at various plant spacings. The space between rows and that of individual plants was 0.3 m × 0.5 m, 0.5 m × 0.5 m, 0.5 m × 1.0 m, 1.0 m × 1.0 m; the space between rows and that between individual plants of semi-shrubs were 0.3 m × 0.5 m, 0.5 m × 0.5 m, 0.5 m × 1.0 m; these densities were so high that the plants withered or grew unhealthily for lack of moisture. From 1964 onwards, a strip form of revegetation was adopted and certain spaces between strips have been arranged to widen the row spacing to allow access to more moisture and organic matter. The strip arrangement was both practical and beneficial.

Because of differences in formation and natural conditions in various sandy areas in China, the characteristics of measures for controlling shifting sand are different. The comprehensive models for the prevention and control of sand encroachment in oases, the desertified land of dry steppe and desertified steppe and along railways and highways have been successfully developed in China. The main models Ming (2006) are as follows.

5 Biological Models for Protecting Different Land Use

The integrated shelter system that consist of three parts, which is fixing sand belt for preventing wind erosion on the periphery of oasis, stocking sand belt for breaking wind and stopping the shifting sand along the edge of oasis, and forest network within oases for protecting the farmland. This model is the cardinal pattern of shelter system for sand harm in China. Usually, the shrub and grass belt is 300–500 m wide. The purpose of closing the area is to protect the land surface from wind erosion, and to stop shifting sand. The shrub and grass belt is a first defense for protecting the oasis. Establishing the shrub and grass belt is a pioneering measure for the establishment of the whole system, because shrub and grass belt can be established easily and it can take into effect rapidly. In the early stage after the completion of an integrated system, the shrub-grass belt can stop drifting sand and resist wind erosion, protecting the young trees within the system and the farm land protection tree belt. Generally, the sand-stocking and sand-fixing forest belts are the second defense, which it is from 200–300 to 1,000 m wide in the forward region of dunes where a great number of shifting sands can encroach on oases; it is 50–100 m in the sections where shifting sands are close to oases and the trees can be planted at the base of sand dunes; it is 30–50 m wide in the sections where farmland adjoin semi-fixed dunes; and it is 10–20 m wide in the sections where oases border on Gobi where sand source is not rich.

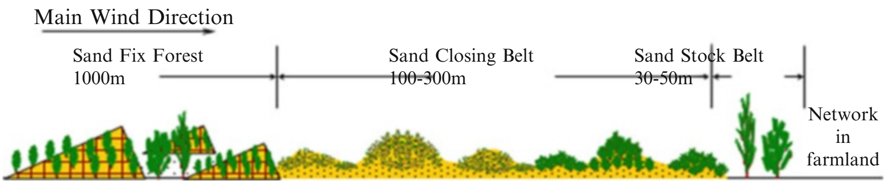

Fig. 3.4 An integrated approach to sand fixation in an artificial oasis threatened by encroaching sand dunes

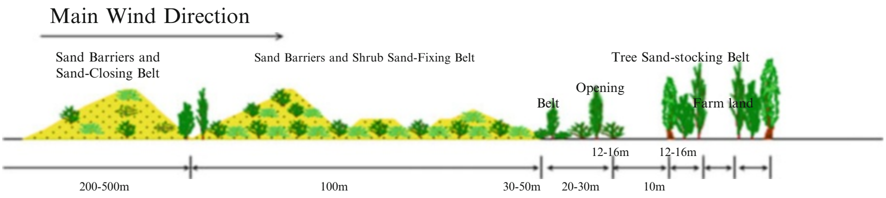

Fig. 3.5 Comprehensive Shelter system in Gaotai county, Gansu

5.1 Oasis Protection

There are some example models for protecting oases:

Example 1. Comprehensive control of shifting sand in Xishawo, Minqin County (Fig. 3.4).

5.2 Tree Belts to Trap Sand

Establishing the fixed and semi-fixed dunes (constituted by the sand mounds covered by *Tamarix laxa* and *Nitraria tangutorum* close to farmland, forms the belt for protecting natural vegetation. In the section attaching to mobile sand dunes on the periphery of closing belt, Russian olive and poplar are planted as patches in lowlands among dunes to encircle the dunes, clay or wheat straw barriers are constructed in grid or line and *Haloxylon ammodendron* is planted within barriers on dunes.

Example 2. Comprehensive control of shifting sand in northern bank of Heihe River in Gaotai County (Juba and Shiba villages as examples) (Fig. 3.5).

Sand-stocking forest belts, 12–16 m wide per belt, are planted with trees (*Populus gansuenis and Elaeagnus angustifolia*) in the sand area close to farmland; there is an interval of 10 m between neighboring belts. Forest multi-belt for stocking sands is planted with trees and shrubs along the forward line of mobile dunes. Based on the construction of sand barriers, shrub forest for fixing shifting sands is planted with

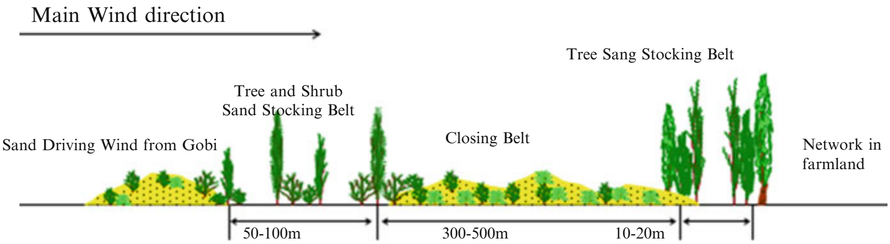

Fig. 3.6 Comprehensive system for sand control near Aydingkol Lake, Turpan county Xinjiang

Haloxylon ammondendron and *Calligonum spp*. on mobile sand dunes within 100 m out of sand-stocking forest belt. Combined with the placement of sand barriers, sand-closing belt for rehabilitating natural vegetation whose width is 200–500 m is placed on the periphery of sand-fixing belt (Fig. 3.4)

Example 3. The area surrounding Aydingkol Lake in Turpan County

Turfan is an arid area in Xinjiang. Irrigation water is often available in late summer and autumn after the crops have matured. This water can be used to irrigate the sandy land and afforest it outside of sand-closing belt, the forest belt that is disposed in multi-belt and where wide rows alternate with narrow rows for stocking blown sand is planted with trees (*Populus alba var. pyramidalis, Elaeagnus angustifolia, Ulmus pumila* etc.) and shrubs (*Tamarix spp.*) on it. Shelter forest systems of oases in sandy desert include closing belt for grasses (shrubs) established along front line of mobile dunes, land-break and sand-stock forest belt along the edge of oases and forest network in farmland in oases (Figs. 3.6 and 3.7).

5.3 Planting Forest on Lowlands

This measure is common in Mu Us sandy land in inner Mongolia, this is called "blocking shifting sand dune in front and dragging it from behind". The Wushenzhao plain in the north of Mu Us sandy land is taken as the example here.

The actual method is to take the trees as major species to afforest in lowlands among shifting sand dunes so as to break up and surround mobile sand dunes, plant sand-fixing plants on lower (1/3) part of the windward slope of the dune to form "dragging dune from behind", thus the middle and upper parts of the wind ward side is eroded by wind constantly, the height of dune declines constantly even a concave is formed by wind erosion in former upper part of dune, at this time, sand-fixing plants are planted on the concave (Fig. 3.8). This continues until the whole sand dune become even. In general, this process takes about 5 years, thus the coverage of controlled sand land could increase to over 50 %, as shifting sand is stabilized.

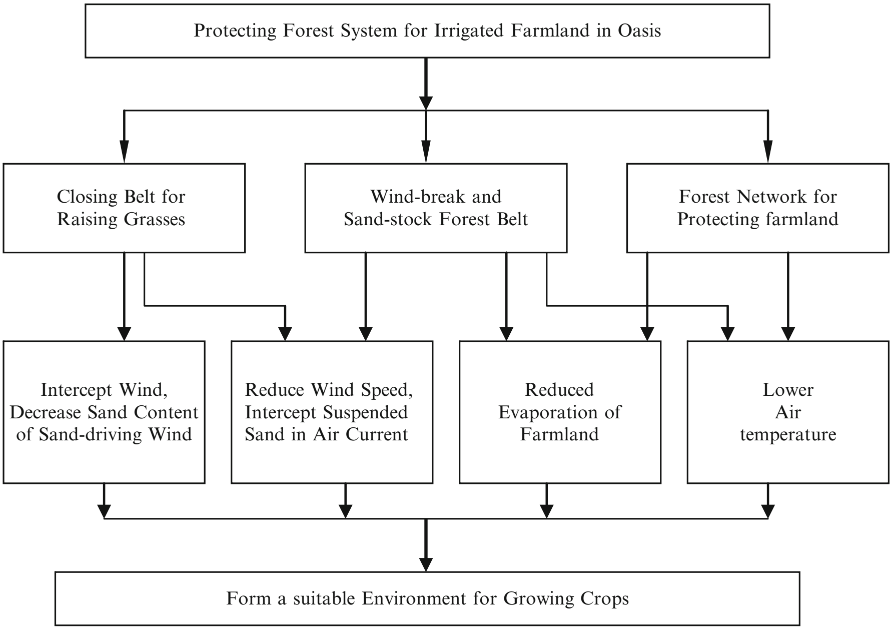

Fig. 3.7 Flow chart for Shelter forest system to protect the artificial oases

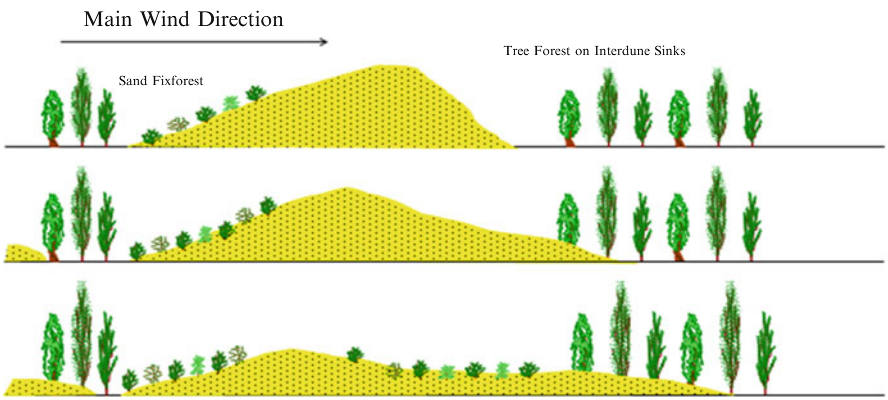

Fig. 3.8 "Blocking shifting sand dunes at front and dragging at back" a schema for successful application in the Wushenqi area of the Mu Us sandy land in Inner Mongolia

5.4 Trees in Combination with Shrubs to Control Shifting Sand

This approach is proven practice in the Horqin sandy land of NE China. Tree patches are planted in the swales between the dunes, simultaneously with planting sand binders (mainly shrubs) on sand dunes and later adding a pine (*Pinus sylvestris*

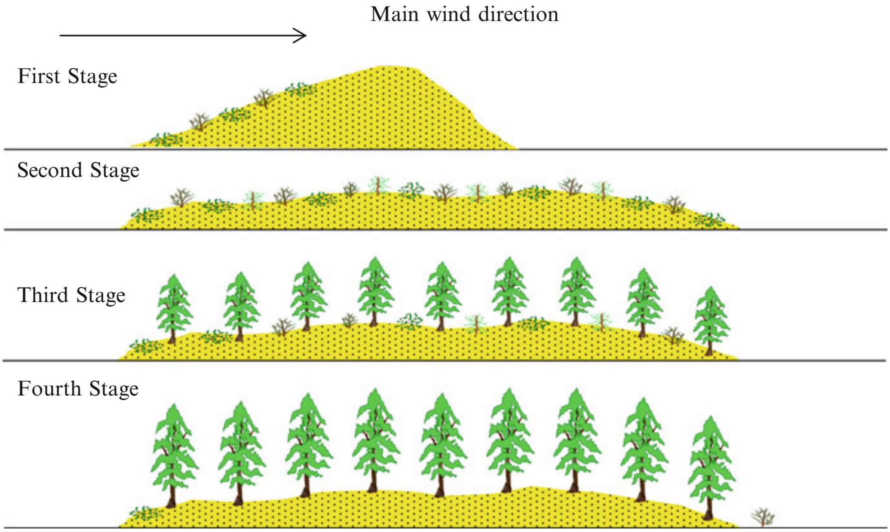

Fig. 3.9 Sand fixation and afforestation on shifting sand in Zhanggutai, Horqin sandy land, Laoning, NE China

var. mongolica) grove to form woodlands. Experience of Zhanggutai district, Liaoning province, shows that measures for arresting mobile sand dunes include the following: first, the belts of *Artemisia halodendron* saplings or the cuttings of *Salix gordejevii* are planted on the middle-lower part of windward slope to prevent wind erosion, or else, *Lespedza dahurica* or *Caragana microphylla* may be used for the same purpose, then, sand-fixing plants should be cultivated when the dune top is leveled off. After about 3 years when the sand surface is relatively stabilized it is the high time to plant *Pinus sylvestris var. mongolica* between the shrubs or herbs that are already established on the sand.

The shifting sand dunes in Zhanggutai district are transformed into the fixed sand land of *Pinus sylvestris var. mongolica* grove by the measures outlined above (Fig. 3.9).

6 Suitable Biological Models for Protecting Transportation Corridors

There are some railways and highways intersecting desert regions. In order to guarantee operation of railway and highway communications in the desert, besides selecting ideal routes, available measures should be taken to fix shifting sand. Establishing a protective system in the form of "sand-stocking, sand-fixing and sand-transporting" along the sides of road is usually adopted in the control of sand hazard along the roads. So-called “stocking” is to erect artificial sand barriers at some distance from the road on the windward side of road to stock shifting sands; “fixing” is to adopt engineering measure in combination with plantation of sand binder on the sand dunes close to road along sides of road to stabilize the surfaces of dunes; “transporting” is to build a streamline section for highway, sand guiding bank, sand transportation bank or shallow trough to promote wind velocity and prevent or lessen sand accumulation. These measures are applied according to different natural conditions and types of sand (Squires and Warsame 1998).

There has been experience in managing sand dunes along both sides of transport corridors including railways and highways so as to protect railroad beds from wind erosion and sand accumulation. This action will guarantee the safe operation of transportation (see Chap. 2 for the mechanical methods used).

The biological approaches are widely used for stabilizing shifting sands along railways/highways in the sandy deserts and other affected regions of Northern China. Revegetation along railways/highways for controlling sand encroachment and sand accumulation, and the plantation of trees or shrubs along railways and highways to decrease wind velocity and increase roughness of surface to prevent the traffic lines from sand disasters are possible even without irrigation. Such examples are available at Shapotou Station, Zhongwei Country, Ningxia Hui Autonomous Region and Cross-Taklimakan Desert Expressway, Xinjiang.

The initial step to fix shifting sands, measures for planting vertical mechanical barriers were adopted to prevent dune surface from sand transport and dune movement in given cases (see Chap. 2 for detail).

After the mobile sand dune surface were stabilized some selected species were transplanted from nurseries. The transplants are wrapped with dried plant branches to deter grazing and protect against wind. These newly planted biological complexes are fenced for years to avoid animal trampling, to increase the silt crust on vegetated dune surface and slow down the wind velocity.

6.1 Control of Sand Harms Along Railway in Semi-Desert Region

For railway lines running through the border zone of semi-desert where shifting sand dunes stretch and undulate, there are protective belts built and forming a protective system in combination of “sand-fixing, sand-stocking and sand-transporting” on both sides of the road in proportion to the yearly advance rates of sand dunes. The Zhongwei-Gantang section of Baotou-Lanzhou Railway on the southeastern fringe of the Tengger Desert is such a case. There they built a 500 m wide belt on the side of the main wind direction and a 200 m wide belt in the secondary wind direction which widespread straw checkerboard sand barriers (1 m $\times$ 1 m) with planting sand-fixing plants in grids (Fig. 3.10). Besides providing gravel protection on the slopes of the road and gravel platforms on both sides of the road for transporting sand

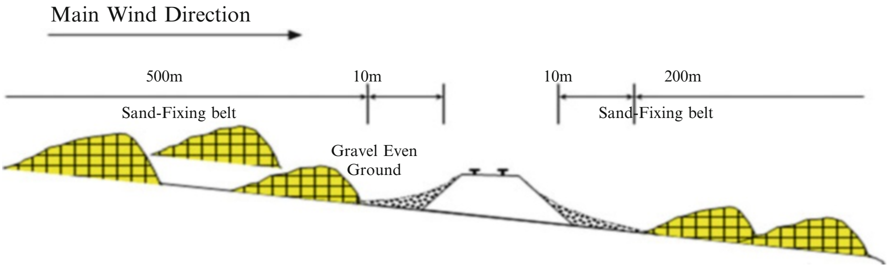

Fig. 3.10 Structure of a comprehensive protection system developed in the Shapotou section of Baotou-Lanzhou railway line

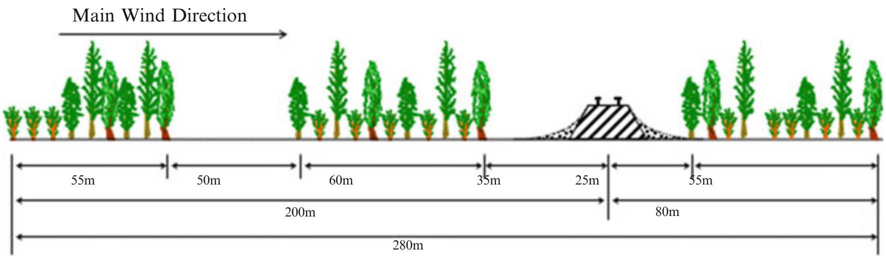

Fig. 3.11 Structure of sandbreaking forest in the Junkeng-Erdaogou section of the Lanzhou-Xinjiang railway

and checking the advance of sand dunes. Above-mentioned measures are adopted extensively in this section of the railway so as to guarantee the smooth operation of railway in the desert.

6.2 Control of the Hazard of Sand-Driving Wind from Gobi Along Railway Lines

For railway lines running through arid zone and Gobi where sand-driving wind constitutes a serious menace, "sand-stocking" is taken as main protective measure. The Yumen section of Lanzhou-Xinjiang Railway is in such a case. In order to play the sand-stocking function of shelter forest belt, a multi-belt forest and an opening belt is the best choice. At wind gaps where sand drift is strong, 2–3 rows of sand barriers should be placed in front of the shelterbelt to block the sand drifting (Fig. 3.11).

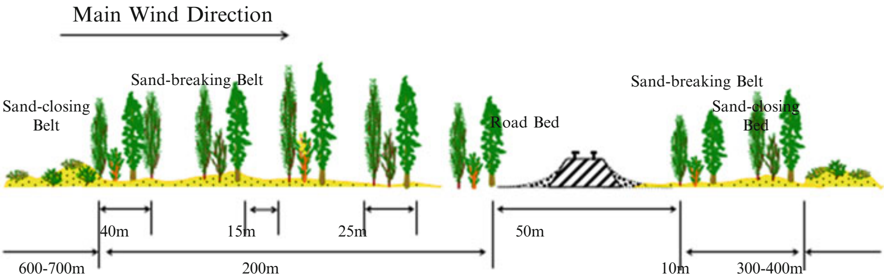

Fig. 3.12 Structure of the shelter belts in Ganqika section of the Dalushan-Zhongjiatun railway line, Inner Mongolia

6.3 Control of Sand Hazards Along Railway Line in Dry Steppe

There are some railway lines running across mobile sand areas and fixed and semi-fixed sand dunes in steppe, e.g. Dalushan-Zhengjiatun line through Horqin Sandy Land in Inner Mongolia and Laoning. Where the railway line traverses an area with mobile sand dunes, various *Populus* trees are planted on the swales between dunes and flat sand lands are planted with sand binders (e.g. *Salix gordejevii, Artemisia halodendron, Caragana microphylla* etc.) The shelter belt on the windward side is 200 m wide, and divided into 3 forest belts with width of 25 m per belt of first to fourth forest belts, 40 m of fifth from road bed, and distances of 15 m between neighboring belts. The widths of 600–700 m on windward side and 300–400 m on leeward side as closing belt exist (Fig. 3.12).

6.4 Control of Sand Hazard Along Highways

For highways that pass through desert areas where the conditions are favorable for sand-fixing plants to grow, measures such as planting road-protective forest belts along the line and fixing sand dunes by planting shrubs (*Artemisia ordosica, Salix psamophilla* etc.) should be adopted and properly combined. For sectors of fixed and semi-fixed sand dunes, the best and easiest way is to fence off the dunes to grow grasses and forests. This method has been widely adopted on most highways in Mu Us Sand Land, Inner Mongolia.

In areas where sand source is rich and shifting sand dunes prevail a combination of mechanical and biological measures is adopted. A wind-leading panel is erected at the shoulder of highway on the windward side of highway. It may be perpendicular or lean forward (angle of inclination is 60°–80°). There is a wind exit between the ground and the panel. The recommended width of a panel is 1.5–2.0 m, and the

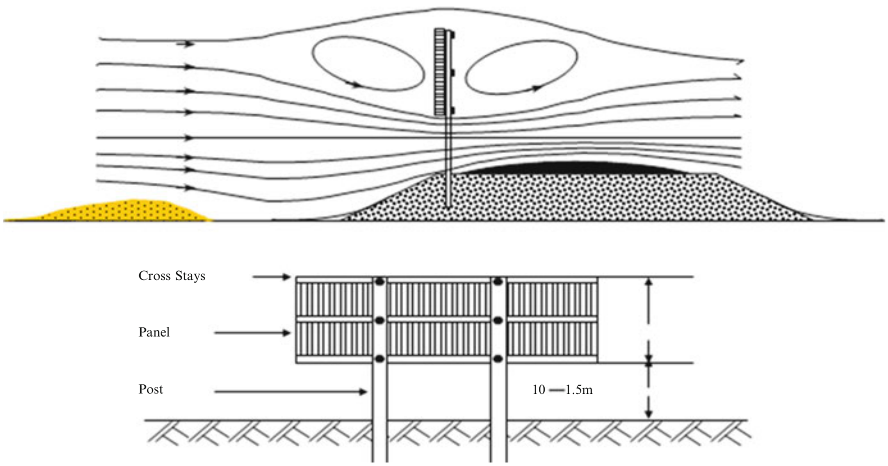

Fig. 3.13 Structure and placement of wind-leading panels for highway protection

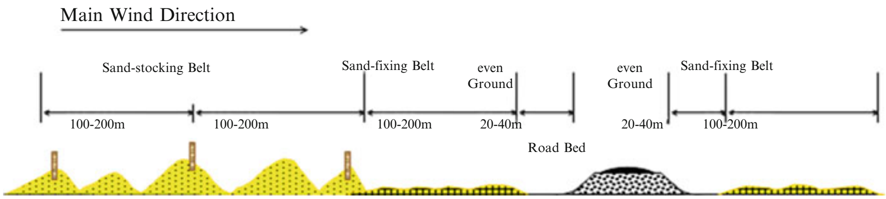

Fig. 3.14 Comprehensive Shelter system on two sides of a highway

recommended height of the wind exit is 1.0–1.5 m. The experimental data of wind tunnel on wind-leading panel show that a proper ratio of the width of panel to the height of wind exit is 1 to 0.7.

The best and easiest way is to establish an engineering protective system in combination of "fixing, stocking and transporting". The comprehensive protective system is disposed by erecting several rows of standing sand barriers as outmost sand-stocking belt on the windward side of highway to check the shifting sand, then, placing the straw-checkerboard sand barriers of 100–200 m in width and planting sand-holding species such as *Haloxylon ammodendron, Calligonum mongolicum* etc. The components of the system are (i) a sand-fixing belt to stabilize mobile sand dunes and lessen the strength of blown sand, (ii) paving of a flat belt close to the roadbed and (iii) streamlining the section of roadbed so that shifting sand does not-accumulate but instead it passes over the road surface.

Adopting the above engineering protective system (Fig. 3.14) on Ruoqiang-Qiemo Section of Qinghai-Xinjiang highway and Urumqi-Yining highway has achieved success.

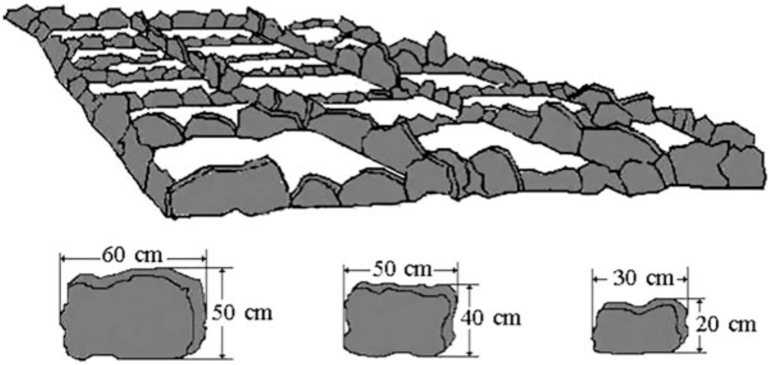

Fig. 3.15 Mechanical barriers made of clay have proved to be successful in some areas. Clay 'tablets' of various sizes are used in mixtures (as shown)

6.5 Control of Sand Hazard Around Factories or Mines

The control of blowing, shifting sand around Jilantai Salt Lake is taken as an example here. The Jilantai Salt Lake lies in the southwest part of Ulan Buh Desert around which the shifting longitudinal dunes and sand mound covered by *Nitraria tangutorum* prevail. The northwest is the main wind direction in this area. The area covered by sand reached 10.8 km^2, making up 29 % of the total salt lake area. In view of this situation, a comprehensive shelter system around the Lake has been established. The measures adopted are follows.

6.5.1 Enclosure Method for Protecting Factories

In the spring of 1984, the wire fence of 27 km in length was installed, the closed area reached 16 km^2. An investigation in 1985 showed that the vegetation coverage of the closed area increased from 20 to 39.4 %; the sand quantity (0–10 cm above ground surface) in the air current in the closed area, compared with the check plot, decreased by 75 %. A great amount of sand was kept in the closed area. Sprinkler irrigation was used to reclaim the surface of sand dunes in this area. This improved the rehabilitation and regeneration of vegetation cover in the closed area.

6.5.2 Adopting Engineering Measure

The clay checkerboard barriers (1×1 m) should be built at the feet of mobile longitudinal dunes (Fig. 3.15) close to the Lake, and combine with closing and protecting natural vegetation and establishing artificial vegetation to form the measure of “blocking shifting sand in front and cutting off the sand source from behind” so as to stop the encroachment of blown sand to the Lake.

6.5.3 Planting Sand-Fixing Forests

Sand-fixing forests were planted on the area where the original natural vegetation and terrain were not disturbed, in the light of the principle of “planting suitable trees in accordance with local natural conditions”, after two and a half years the vegetation coverage reached 45 %. Sand-fixing forests were planted on the sand land formed by leveling off the sand mounds covered by *Nitraria tangutorum.* By contrast, the undisturbed native vegetation coverage only reached 27.5 % during the same period. The dune-leveling system was more effective.

6.5.4 Watering Shifting Sand Dunes Through Sprinkler in Winter

The surface of sand dunes was frozen after irrigation by sprinkler; as a result the wind erosion and movement of sand dunes were avoided. In addition, the water content in the sand dunes was ideal for afforestation next spring. The comprehensive protective measures have been carried out in Jilantai Salt Lake since 1984. The average annual amount of sand (1984–1986) entering the Lake had decreased by 908,000 m^3 (from 1,275,000 to 367,000 m^3), compared with that 3 years before 1984.

6.6 Control of Sand Hazard to Reservoirs

The control of sand hazard to Jiefang Village Reservoir in Jingtai County of Gansu Province is taken as an example. The Jiefang Village Reservoir adjoins Baishuiquan Desert on the west, northwest and north. The northwest is the main wind direction. The Baishuiquan Desert encroaches upon the Reservoir and constantly spills the sand into the Reservoir. The annual amount of sand entering into the Reservoir reaches 300,000 m^3. The shelter system around the Reservoir is necessary to be established. Three rows of standing sand barrier with an interval of 3–6 m between the neighboring barriers on the part of windward slope (2/3 up the windward slope) of fourth barchan chain (from the Reservoir) 1,300 m away from the Reservoir were set up. The windward slope became steeper after the wind season (usually late winter-early spring each year). The bare sand surface on the windward slope (down 2/3 the windward slope) was paved with gravels from swales between the dunes to form a permanent artificial sand-accumulating bank, by which shifting sand was piled up and the sand source was cut off.

7 Conclusion

According to the 4th Report to the UNCCD the affected lands are mainly distributed in arid, semi-arid and dry sub-humid areas in the western part of Northeast China, North central China and most of northwest China. China and her people have a long history to combat desertification, in particular, since the foundation of New China. The government is concerned about desertification and more attention has been paid and effective efforts have been developed for fixing sand and for combating desertification. Some acceptable and practical techniques, successful demonstrations and rich experiences as well as extension service models to combat desertification and manage dry lands have been developed at community, local and national levels. At present, at the periphery of both sandy desert and Gobi areas, sand encroachments have been controlled and local ecological restoration and environment protection have been promoted in many regions. The social economy has been developed and local people's living standard have been greatly improved (Wang et al. 2012)

Some successful and biological measures for different land uses were developed for such as agricultural areas, highways, railways, roads, cities, industrial factories and mining areas. Suitable plant species were chosen on the basis of their capabilities in these kinds of harsh environments. Plantation techniques and the seed treatments like sowing, seedling, air seeding were perfected and successfully used for protecting people and property. Shelter belt systems and practical models for the hilly and flat desert areas are available for application in desertified areas world wide.

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Part II
Deserts and Desertification in Three North African Countries

The three chapters in this part deal with deserts and desertification in North Africa with examples from Egypt, Libya, Morocco and Egypt.

North Africa has a Mediterranean climate with hot dry summers and cool wet winters. Large areas of each of the three countries is classified as desert. The land use is governed by water availability. Successful cropping in Egypt and parts of Libya is almost totally reliant on irrigation. Land degradation in the form of water logging and salinity are common problems in irrigated croplands. Rain fed farming prevails over much of Morocco and parts of Libya. Soil loss from wind and water erosion and overgrazing of the steppes by livestock are common immediate causes of desertification.

Chapter 4
Libya: Reversal of Land Degradation and Desertification Through Better Land Management

Ali Mansour Saad, Noresah Mohd Shariff, and Sanjay Gariola

Synopsis This chapter characterizes desertification in Libya, summarizes its causes and outlines efforts to combat desertification. The need to mainstream sustainable land management into land use planning is highlighted.

Key Points

- Libya is characterized by a desert type environment and more than 95 % of the country is desert or semi-desert. The processes of desertification have been aggravated by human activities coupled with climatic conditions. This intensification of desertification is believed to affect regional as well as global climate. Currently, desertification is one of the main environmental issues in Libya affecting environment and its resources.
- Among others, overexploitation of natural resources, inappropriate land use planning, insufficient water resources etc. are the main factors escalating the process of desertification and deteriorating environmental quality. Mainstreaming sustainable land management into land use planning has been considered a viable solution to moderate the effects of desertification and rampant usages of natural resources. However, this requires quantifying the severity of desertification by means of identified causative factor.
- Development of indicators of desertification process by means of using temporal satellite data coupled with ancillary data need to be attempted to establish a monitoring system to manage desertification in more sensitive areas. Moreover, environmental and livelihood implications of increasing desertification need to be addressed in order to promote regional economic sustainable development.
- Efforts to combat desertification began in the early 1960s, serious measures have been taken to combat desertification in Libya by the best possible means.

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These measures were part of a broad policy in the framework of National Plan for Agricultural Development which takes into account the objectives of local development on the one hand, and harsh environmental conditions prevailing in the country on the other. These measures include curbing sand dunes, establishment of windbreaks, reforestation of fallow forest land, establishment of terraces to combat soil erosion, preservation of rain water on sloping agricultural land, and follow the special agricultural cycle to maintain soil fertility, especially in the areas of cultivation of grain, as well as the protection and improvement of natural pastures.

Keywords Desertification • Human impacts • Libya • Natural resources • Sustainable development Mediterranean Sea • Mediterranean • Saharan • Climate • Climate change aquifers • Irrigation • Camels • Water deficit • Groundwater • Olives • Vegetables

1 Introduction

Libya occupies a large area of the northern part of the African continent (Fig. 4.1) with an area of about 1,600,000 km^2 (Libyan General Planning Council 2003). Libya is located between 18° and 33° N and 9° and 25° E. Its climate is mainly determined by contrasting Mediterranean and Sahara climates (El-Tantawi 2005). The Mediterranean Sea is regarded as the border from the north with a coast that has a length of 1,900 km stretching from east to west (Abu Luqmah 1995). The population of Libya in 2006 was about 5,657,700 million people according to the general census of population (Libyan General Agency of Information and Documentation 2006).

The vast area of the country (Table 4.1) and the difficult natural environment makes it impossible to develop the bulk of the area. On top of that, desert conditions, water scarcity, and harsh climatic conditions have created barriers which impeded the expansion of human activity and development. As a result, the cultivated and populated areas are small and limited in comparison with the total area of the country. The desert climate prevails in the largest part of the country, with the exception of only a narrow strip extends along the Mediterranean which includes the coastal plains and the Northern highlands where the Mediterranean relative cold and rainy in winter with two transitional seasons which are spring and autumn.

However, most of Libya experiences long arid months and very few humid months. Temperatures range between high to very high in the summer and moderate to cooler in the winter and reaches the highest during the summer in August, while the lowest is recorded during the winter season in January. The climate of Libya is characterized by absolute aridity. The period of rainfall is almost limited to a few months of the year (i.e. October to March) on the northern areas dominated by a typical Mediterranean climate. About 90 % of the annual rainfall occurs during the cold half of the year, and nearly half of the amount falls during the months of January

Fig. 4.1 Map showing Libya and its neighbors and its geographic location in Africa

and February (Emgaili 1995). Rainfall is the main feature of precipitation in Libya; nonetheless it is very erratic and limited (El-Tantawi 2005). Given this sporadic rainfall pattern, agriculture production in Libya is highly reliant on irrigation (Fig. 4.2).

Rainfall in Libya is very infrequent, thus limited dependence on rainfall for agricultural production. For example, only 32 % of wheat, 38 % of barley, 25 % of dates, 29 % of pulses, 34 % of vegetables and 24 % of olives are produced under rain-fed conditions (FAO AQUASTAT 2005). Hence, climatic conditions severely limit agricultural production in Libya. Average annual rainfall distribution in Libyan

Table 4.1 Area as per aridity zones of Libya

Aridity zones	Average annual rainfall (mm)	Land Area (000' km^2)	% of total area
Very dry	<50	1,589	90.8
Dry	50–200	130	7.4
Semi-arid	200–400	26	1.5
Sub-humid	>400	5	0.3
Total		1,750	100

Source: ACSAD (2004)

Fig. 4.2 Large-scale center pivot irrigation schemes are a feature of Libya's agriculture

territory is presented in Table 4.1. Hence, Libya like many Mediterranean regions, also experiences more long dry summers and water deficits prevail throughout the year. The annual rate of evaporation is about 1,700 mm near the sea and 6,000 mm in the central and southern regions (Libyan General Planning Council 2003).

Aridity plays a major role in the process of desertification. This has resulted in low vegetation cover, increased soil erosion and land degradation on a large scale and makes the region vulnerable to desertification. Groundwater in Libya is classified into renewable ground water and non-renewable underground water. Groundwater is the main source of water supply in Libya, and represents more than 97 % of the total water consumed. Safe water extraction is estimated at about 3,000 million cubic meters per year (Libyan General Planning Council 2003) and is located in five major water basins (Fig. 4.3).

In general, Libya is regarded as one of the areas with low density of natural vegetation due to lower annual rates and irregular distribution of rainfall (Table 4.2).

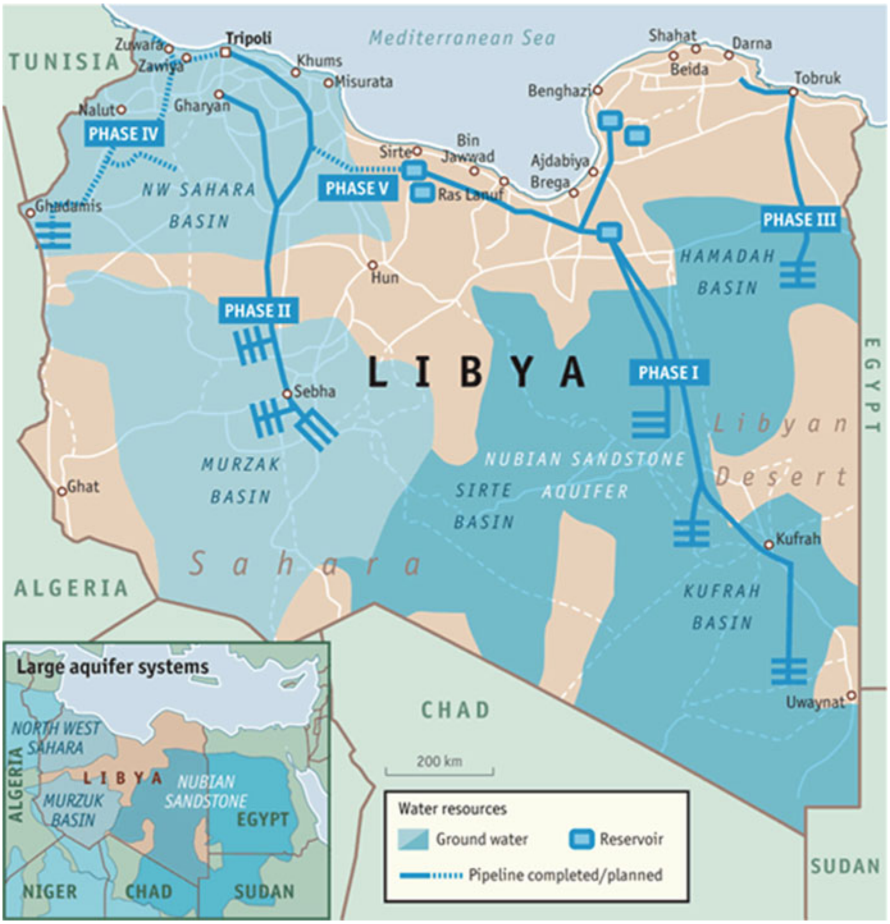

Fig. 4.3 Irrigation depends on exploitation of large aquifers that underlie much of Libya

Due to its particular geographical position and extreme climatic variations, Libya is experiencing a serious problem of land degradation and desertification. Climate change predictions for North Africa, including Libya, show rising temperatures with potentially grim impact on the region's already stressed resources including water and food (IPCC 2007). Urbanization coupled with the loss of fertile soils, overexploitation of water resources, overgrazing, destruction of natural vegetation and rapid land use change are important reasons for the environmental problems in Libya. Despite the vast area of the country, most of this area lies within the warm desert climate that prevails in most of the northern part of the African continent where the desert covers 98 % of its territory (BinKhayal 1995). The only exception is a narrow coastal strip that extends along the Mediterranean Sea and some mountainous areas in the north and south, where rainfall in sufficient for the growth of natural vegetation and cultivation of certain crops and fruit trees.

Table 4.2 The water situation in Libya (1990–2025)

Sector-wise demand	1990	2000	2010	2020	2025
Required: (m Cub. meter)					
Agriculture	4,275	4,800	5,325	5,850	6,640
Drinking	408	647	1,015	1,512	1,759
Industry	74	132	236	422	566
Total	4,757	5,579	6,576	7,784	8,965
Available:					
Renewable water	500	500	500	500	500
Non-traditional sources	105	127	155	188	208
Artificial river	–	1,642	2,226	2,226	2,226
Total	605	2,269	2,881	2,914	2,934
Deficit	4,152	3,310	3,695	4,870	6,031

Source: Fadel and Abu Luqma (1995)

In spite of the small population of the country, the concentration in the northern region caused anthropogenic pressure on the area, especially in marginal cropping areas which resulted in serious environmental problems such as degradation and low levels of groundwater, seawater intrusion into fresh water, degradation of agricultural land and low productivity in many crops (El-Tantawi 2005).

Accelerated land degradation in agricultural areas is pushing agriculture deeper into the desert margins. Not only is agriculture itself doomed, but also alternative uses of the desert, such as controlled grazing, conservation of biodiversity, recreation, eco-tourism and tourism, are being displaced (Portnov and Safriel 2004). Impairment of agriculture ecosystems due to desertification often leaves behind an ecosystem that ceases to provide environmental services, and sometimes is even impossible to rehabilitate.

2 Causes and Consequences of Desertification and Land Degradation

Libya has witnessed enormous development in various fields, particularly in the sectors of agriculture and industry. However, such development has had negative effects on local ecosystems, especially in sensitive and fragile areas due to change in production patterns, and the need to provide food requirements for the growing population. Consequently, this led to the intensification of pressure on already limited natural resources, and thus escalating land degradation and desertification problems. There are several natural and human factors that cause land degradation in Libya (Ben-Mahmoud et al. 2003).

The Natural factors include changes in climate, mainly rainfall, wind and temperature. Climate varies from one setting to another in response to changes in external and internal influences in the atmosphere (Emgaili 1993). There have been significant climate changes through geologic time on the African continent, in which wet and dry cycles alternated. Dry periods led to the emergence of the Sahara, and the current climate of the area is a continuation of the dry climate, which began since the emergence of the Sahara, with a general tendency towards more long-lasting droughts in the past years. Therefore, the wind and water erosion are among the natural and fundamental factors causing land degradation and desertification in Libya (Emgaili 2003). Although climatic factors play an important role in the spread of the phenomenon of desertification, yet human activity causes the deepening of the effects of drought on environmental resources and human beings.

Many human factors are combined contributing to the deterioration of environmental conditions and the occurrence of desertification in Libya. The increasing pressure of population on natural resources (e.g. water, soil, vegetation), poor management and over exploitation of natural resources by entities or individuals, mainly led to the desertification. Anthropogenic factors causing deterioration of soil and vegetation in Libya include: (i) overexploitation of water resources (ii) land transformation for agricultural uses (iii) Deforestation and the removal of natural vegetation, (iv) over-grazing in marginal areas (v) Misuse of the soil for agricultural purposes, and urbanization (El-Tantawi 2005; Emgaili 2003; Libya General Planning Council 2003).

Desertification along with the degradation of rural, natural and pastoral areas leads to the impoverishment of the nomads, shepherds and farmers in dry areas. This process also leads to the migration of pastoralists, nomads and residents of rural areas to cities in search of livelihood and the desire for a better life. Such a process contributes to increase pressure on cities and resources and affects the economic and social life of the nomadic tribes (Nahal 1987). Desertification results in a variety of negative environmental, economic, social impacts, directly or indirectly. Consequently the productivity of natural pastures, forest and agricultural land is decreasing. In periods of successive drought the problem is considered acute and studies have shown that the production per hectare of grain in the dry and marginal areas in the Arab world has significantly decreased. Moreover, deterioration of the pastoral environment causes a decline in the productivity of livestock and thus reduces the productivity of meat and milk.

Desertification is accompanied by deterioration in soil fertility, change in its physical and chemical properties and vulnerability to erosion by water (Arab League 2003). This may cause a decrease in the volume of agricultural resources and a decrease in the area of arable land, which ultimately has negative socio-economic consequences. The shrinking of forest lands and natural pastures due to deforestation leads to increase the number of animals – far exceeding the carrying capacity of grazing lands, leading to the import of large amounts of animal feed from abroad, and consequently causes economic losses. Similarly the loss of forests and natural reserves, cause damage to national income as a result of the loss of revenue from products (Nahal 1987). Desertification also leads to many environmental impacts such as the formation of sand dunes and sand encroachment on urban areas and farms, roads and railways. Most notably desertification leads to air pollution, dust, and reduced biodiversity and other negative environmental effects.

It is clear that desertification has serious ecological, socio-economic and environmental consequences. Hence, the lack of appropriate strategy to combat and fight against desertification using various ways and means at all levels may lead to devastating consequences. The most serious consequences include the degradation and destruction of natural resources, decrease of productive lands (agricultural and pastoral) and reduced productivity; soil salinization and erosion, mobilization of sand dunes, habitat fragmentation and extinction of valuable species, occurrence of dust storms that have severe environmental impacts on plants, animals and humans and migration of people to cities. The major consequence of desertification at the local and global level is the reduction in biodiversity, since it contributes to the destruction of the habitats of animal and plant species and micro-organisms (Abahussain et al. 2002). It is also expected to encourage the genetic erosion of local livestock and plant varieties and species living in fragile ecosystems, Libya is no exception.

3 Efforts to Combat Desertification

In order to combat desertification continuous monitoring is essential and currently the use of the remote sensing technology to monitor desertification has proved to be the most efficient approach (Hassan 2004).

Since the early1960s, serious measures have been taken to combat desertification in Libya (Ben-Mahmoud et al. 2000). These measures were part of a broad policy in the framework of National Plan for Agricultural Development which takes into account the objectives of local development on the one hand, and harsh environmental conditions prevailing in the country on the other. These measures include fixing mobile sand dunes, establishment of windbreaks, returning fallow land to forest land, establishment of terraces to combat soil erosion, retention of rain water *in situ* on sloping agricultural land, and using crop rotations to maintain soil fertility, especially in the cereal-growing areas, as well as the protection and improvement of natural pastures (Nahal 1987) (Fig. 4.4).

In spite of the success of some attempts to achieve the desired objectives, others did not meet the same success due to the lack of relevant laws and regulations concerning the protection of the environment (Libyan Department of Urban Planning 2005). However, adopting better land use management practices could slow down the desertification process.

Libya has adopted a lot of measures and actions to reduce the desertification during the past four decades. Major desertification controlling strategies can be summarized in the implementation of a range of diverse projects by government in many areas (i.e. forest, pastures, sand dune fixation, soil and water conservation, resistance to erosion and integrated agricultural development).

Fig. 4.4 Rehabilitation of degraded rangelands can involve planting fodder species that provide an intake of green material and also protect the soil surface. The photo shows a plantation in an 100 mm zone in Libya (Photo B.E. Norton)

4 Conservation of Water Resources

Libya has given a great attention to development and conservation of water resources by adopting a short term and long term strict policy to prevent a serious drain of water resources.

There are many other actions that contribute to the protection of soil and maintain soil fertility, such as, following the method of crop rotations to maintain soil fertility, especially in areas of expansion in the cultivation of grain; reforestation of waste lands; protecting and improvement of natural pastures; the creation of economic non-agricultural activities, especially in areas threatened by agricultural depletion or degradation of quality (Libyan Department of Urban Planning 2005). Libya has paid a great attention for pastures improvement and development as well as the establishment of pastoral projects based on scientific methods to ensure the preservation of ecological balance.

Attempts have been made to regulate grazing and rehabilitation of degraded lands by a number of programs. Considerable efforts are made to reforest lands threatened by erosion and desert encroachment in order to maintain the natural ecological balance. These include protecting land and soil, Special attention goes

Fig. 4.5 Plantations of *Atriplex* have been used with success. The green leaves are rich in protein and provide a useful supplement in late autumn or in drought times, if an energy source such as straw is available (Photo B.E. Norton)

to forest land where measures such as such as bans on cutting of forests and the development of the existing forests to increase their productivity, establishment of nurseries to meet the need for seedling trees, supporting small forest planting, windbreaks, and protective barriers, as well as meeting the needs of public projects when establishing new forests. Filling the requirements of afforestation and roadside plantings are amongst the important efforts. Moreover, determining access rights, and strict bans on the felling of some forest species, protection from insect damage, and the organization and regulation of grazing (number of animals, entry and exit dates) in natural forests are among significant initiatives (Libyan General Planning Council 2003). For reforestation of degraded and deforested areas to compensate for the past losses, the country has witnessed campaigns of tree planting in the last decades, including revegetation of most of the desertified and degraded lands for the purpose of balancing natural ecosystem (Figs. 4.5. and 4.6), land rehabilitation, establishment of national parks and wildlife reserves to maintain biodiversity and prevent extinction of rare animals and plants, and issuing legislations and laws for the protection, development and investment in forests.

Fig. 4.6 Furrowing to catch water and allow germination of wind blown seeds has been tested in Libya. Creation of surface roughness reduces run off and reduces wind velocity at or near the soil surface (Photo B.E. Norton)

5 Establishment of Legal Principles and Enactment of Legislation

Libya has ratified important international agreements on environment, like biodiversity, climate change and desertification. There are several laws to protect the environment, natural resources including laws on use of arable land, pasture land, water (both surface and groundwater) protection of renewable and non renewable natural resources and urban development. A few of these laws are summarized in Table 4.3.

Because of these and other laws and regulations, it was possible to achieve many of the objectives of combating desertification and halt desert encroachment, and maintain the ecological balance while conserving biodiversity. Implementation of existing legislation could go some way to reverse the trend but enforcement is weak. At the operational level. the effectiveness of policy, laws and legislations need to be assessed properly through an appropriate framework. Abahussain et al. (2002) have reported that the land degradation in the Arab Region due to misuse is widespread and is proceeding at accelerating rates. Failures of resource management policies are aggravated by overgrazing, overexploitation of water and land resources, over-cultivation of marginal lands, deforestation, and the use of inappropriate technologies.

Table 4.3 Important Law and Legislations regarding environment and natural resources in Libya

Law and Legislations	Main objectives
Law 15 of 1992	Protection of agricultural lands, pastures and forests and converting them to irrigated agricultural lands
Law 72 of 1988	Establishment of the Arab Center for Desert Research and development of desert communities
Law 15 of 1984	Protection of animals and trees, and to prevent hunting wild animals, and the prevention of trees cutting because of urban expansion
Law 1 of 1983	Agricultural inspection
Law 790 of 1982	Organization of drilling operations and the preservation of water sources
Law 7 of 1982	Protection of the environment
Law 5 of 1982	Protection of pastures and forests
Law 827 of 1980	The establishment of the General Authority for Scientific Research and its bodies specialized in various fields
Law 46 of 1972	Protection of shrub land
Law 26 of 1972	The establishment of a public board of water responsible for proposing public policies and legislations concerning water, and follow up their implementation, as well as overseeing the follow-up projects related to water abstraction, digging wells and methods of using them

6 Constraints and Prospects

Despite the efforts and achievements made, so far the factors and causes, manifestations and harmful effects of desertification need special attention in Libya. Researchers, natural resources managers and conservationists highlighted a number of obstacles and challenges that need to be confronted by all possible means including: (i) Scarcity of water resources and successive seasons of drought, which limit the success of agricultural projects, land reclamation and cultivation (ii) Increasing levels of food deficit as a result of rapid population growth, and the widening gap between production and consumption rates, and the continued expansion of urban areas which causes damage to agricultural production (iii) Erroneous practices of local people and unfettered exploitation of natural resources with no thought about sustainable use (iv) Lax and inconsistent application of the provisions and legal regulations and legislation governing relations between citizens and natural and environmental resources (v) The absence of a comprehensive database of natural resources in terms of importance and restriction for their uses, and (vi) Weakness of skilled manpower and specialized staff in the field of protection of natural resources and combating desertification (Libyan Department of Urban Planning 2005).

7 Climate Change Impacts

Climate change will result in extreme weather events for the region affecting both the intensity and frequency of climate factors such as temperature, precipitation, rainfall and droughts (IPCC 2007). In Libya water scarcity is endemic and changes in precipitation could pose a strain to freshwater resources, vegetation and rate of desertification (El-Tantawi 2005). Currently many areas became prone to land degradation and the situation will only get worse if climate change and human activities continue to accelerate land degradation processes. Climatic factors contribute to both desertification and the scarcity of water and there is no doubt that global warming is exacerbating these problems. Many believe that these problems can be tackled by re-planting tree in shelter belts as a major afforestation programs, planting grasses to stabilize the soil and halt wind and water erosion, and adopting proper crop rotation and use of manure as a fertilizer, as a good farming practices. Rehabilitating all of the desertified land is not economically feasible, some measures although technically possible cost in excess of $4,000 per ha. Prevention is more feasible. If people stop misusing the land and overexploiting resources beyond the carrying capacity, desertification can be controlled to a large extent and management practices can be implemented more effectively. The successful approaches outlined in other chapters of this book are testimony to this and we are also encouraged by the outcomes of land degradation control in the Asia Pacific region (Yang et al. 2011).

8 Conclusion

As the degree and types of desertification varies from one part of the country to another, land management has been acknowledged to be extremely important in desertification prone areas. Understanding the desertification process more explicitly requires detailed knowledge about where desertification occurs (spatial as well as geographic). Advances in remote sensing and the use of indicators such as land cover change are also important here. The UNCCD at COP 8 asked country parties to adopt two indicators of desertification in their reports on progress in combating desertification and accelerated land degradation. These two indicators are *land cover change* and the *number of people living in poverty*.

Climate change is expected to decrease water availability and water quality, increase the impact of droughts, floods and salinity leading to a decrease in soil fertility and loss of vegetation that threats food security. The increasing pressure on resources by people in addition to the severe climate and low soil fertility has rendered ecosystems even more fragile, and in some places their renewal is jeopardized. It is reported that the progression of desertification is making the unaided recovery of vegetation on cleared and abandoned land impossible, so human assistance through soil preparation, use of fertilizer and watering during regeneration and careful monitoring is needed.

The remote sensing technology with its multi-temporal, multi-spectral, synoptic and repetitive coverage can provide valuable information on intensification of desertification, real magnitude of desertification and its changes over time. Therefore monitoring indicators of desertification processes by means of RS/GIS tools is an effective method to understand the temporal and spatial characteristics of desertification process in a more integrated manner. In view of the above, we have recently initiated studies to provide useful information on the prevailing desertification situation in Libya. In particular, the areas having an exceptionally high magnitude of desertification will be delineated with the help of RS/GIS and the occurrences over space and time will be monitored for better environmental management and sustainable development. It is argued that for better management of desertified land, geospatial tools should be used to track land cover changes to create and update maps so we can manage land utilization effectively and sustainably.

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Chapter 5
Desertification and Its Control in Morocco

Y. Hammouzaki

Synopsis This chapter reviews the status of desertification in Morocco. It is divided into three parts. (i) the general context (ii) causes of desertification in Morocco (both proximate and the root causes and (iii) efforts to combat desertification and land degradation (past and planned).

Key Points

- In Morocco, the process of desertification affects large areas. It is more pronounced because the climate is arid and soils are vulnerable to erosion. Also, precariousness of life of the rural populations pushes them to overexploit the natural resources to satisfy their increasing needs, which accentuates the deterioration of surroundings.
- The sectoral approach adopted to attenuate the natural resources deterioration showed its limits because of the increasing amplification of the deterioration. This situation incited the public powers to adopt new orientations of development that result in the strategy of rural development. In this context Morocco finalized a National Action Program (NAP) for Combating Desertification (CD) which constitutes an important stage in the process of its commitments within the UNCCD. The NAP-CD is conceived to promote a strong articulation and a synergism between the sectoral programs through actions of support and accompaniment of the process of combating desertification. Specifically, there is support of actions that promote income-generation, combat the desertification and attenuate the effects of drought, and reinforce the network of monitoring systems. For the implementation of NAP, the institutional mechanism of coordination has been set up) a mechanism for follow-up and assessment of impacts of projects and different ecosystem observations have been initiated. The success of NAP-CD as political engagement and as tool of programming of concrete

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and innovative actions of intervention and implementations will require the mobilization of all available energies.

- Proven practices to arrest and reverse land degradation in all of its forms have been implemented in every region of the country. These include developement of systems of livestock/rangeland integration that provide additional forage and fodder and at the same time increase then cover of plants that can protect the soil, increase carbon sequestration. Several soil conservation technologies have been developed in Morocco and are available for large diffusion but in many cases these technologies have not been permanently adopted. It seems that a large-scale dissemination of these new practices requires some financial incentives that must be sufficiently high to stimulate farmers to adopt the technologies.

Keywords Morocco • Desert control • Afforestation • Deforestation • Clear felling • UNCCD • Atlas mountain • Steppe • Rainfed agriculture • Livestock • Overgrazing • Fuel wood • Barley • Opportunistic cropping • *Atriplex* alley cropping • Algeria • Mauritania • Sahara desert

1 Introduction

In Morocco, the process of desertification affects large areas and over 90 % of the land area is classified as desertified to a greater or lesser extent. It is more pronounced because the climate is dry and highly variable and soils are vulnerable to erosion. The arid and semi-arid high plateau areas of Morocco are fragile environments with weakly structured soils, sporadic and unreliable precipitation, and low productivity. Land degradation is prevalent in the region. Deterioration of rangeland resources and the consequent increase in rural poverty are exacerbated by prolonged and sometimes severe periods of drought. A significant part of the south and southeast is desert extending southward to the northern edge of the Sahara desert.

1.1 General Context

The Kingdom of Morocco is situated in the north west of the continent of Africa, between latitudes 21°–36° N and longitudes 1°–17° W. The country is bordered by the Atlantic Ocean on the West (2,934 km from Cap Spartel in the North to Lagwira in the South), the Mediterranean Sea on the North (512 km from Saidia in the East to Cap Spartel in the West). It is bordered in the East and South by Algeria and Mauritania, respectively (see Fig. 5.1). The total land area is 710,850 km^2 of which arable land is less than 12 % according to the Ministère de l'Agriculture et du Développement Rural.

Fig. 5.1 Map of Morocco showing its location and its neighbors

The country's history is very ancient as attested by numerous prehistoric and historic monuments and artefacts. In historical time, the country has seen a number of invaders and civilizations: Phoenicians, Berber, Carthaginians, Romans, and Vikings. The Arab conquest came in 681. Morocco has existed, as a state, since 788, when the Idris the First was proclaimed king.

1.2 Economy

The population is about 32 million and the growth rate hovers just below 2 % per annum. Agriculture is the backbone of the economy since it contributes 17 % of the Gross Domestic Product (GDP) and provides employment to half of the active labor force. It has benefited as a priority investment sector by the Government during the last four decades. As a result of this policy, 92 large dams have been built with a total capacity of 14 billion m^3. This and other smaller infrastructure, has allowed the irrigation of some 1.2 million hectares (Mha). Major irrigated areas are the Rharb and Loukkos in the NW, the Tadla in the center north of the Atlas, the Haouz in the Marrakech region, the Souss-Massa in the Agadir region, the Ouarzazate and Tafilalet south of the Atlas, and the Low Moulouya in the Northeast. Accelerated land degradation has the potential to increase inflow of sediment to the reservoirs and reduce storage capacity. Soil erosion has serious negative on-site effects, such as a decrease in soil productivity. However, it may also have off-site effects, such as silting of dams. In Morocco more than 50 million m^3 of sediment are deposited each year in dams' reservoirs. This volume corresponds to a loss equivalent to the volume of water needed to irrigate 5,000 ha (AGR/DAF 2001). To efficiently reduce these offsite effects, adequate government interventions are needed. This may include incentives to implement soil and water conservation practices to farmers (see below).

Fisheries is another important sector as it represents 55 % of agricultural food exports and maintains some 400,000 jobs. Handicrafts contribute 10 % to the GDP and offers jobs to about 1.5 million people.

Tourism is of growing importance to the economy. With 2.5 million tourists in 1999, it contributes 7.8 % to the GDP, and helps maintain about 0.5 million jobs. Desertification and active land degradation threaten tourism.

Mining and energy represent 10 % of the GDP. Morocco has the world's third largest deposits of phosphate, but a stagnant market and lower world prices have reduced the contribution made by this previously important export earner. A small manufacturing sector is growing and bringing export revenues. Consumer goods and semi-finished goods now account for about half of Morocco's export earnings. About 15 % of the labor force works abroad, mainly in European countries such as Belgium and France, and the money these workers send back to Morocco helps to offset the country's large foreign debt.

2 Climate

Morocco is characterized by a Mediterranean climate. Rainfall occurs within the cool season, while the warm season is hot and dry over much of the country. However, owing to its latitudinal location, and as well as the influence of the Atlantic Ocean and the Mediterranean Sea, and that of the powerful Atlas mountain ranges between the southern Saharan and the other zones, the climatic conditions are quite diverse. In fact, this diversity made it ideally suited for the bioclimatic classification of the Mediterranean.

The main bioclimatic subdivisions are:

- *Saharan or desert*, with annual rainfall less than 100 mm and erratic. Winter temperatures are mild along the Atlantic coast, but become cool some 10 km inland and cold further inland;
- *Arid*, with annual rainfall ranging from 100 to 400 mm. This concerns the southern fringe of the Atlas mountains, the Moulouya Valley, the Eastern High Plateaus, the Souss plain and the plains north of the Atlas. Winter temperature subdivisions vary from warm (Atlantic and Eastern Mediterranean coast), to temperate, cool and cold. This latter situation is encountered inland in portions of the Moulouya Valley, and more extensively on the Eastern High Plateaus;
- *Semi-arid*, with annual rainfall ranging from 400 to 600 mm. This concerns the major cereal regions such as the plains of Doukkala, Chaouia, Gharb, Saiss, as well as large portions of the Anti Atlas, High Atlas, Middle Atlas, Central

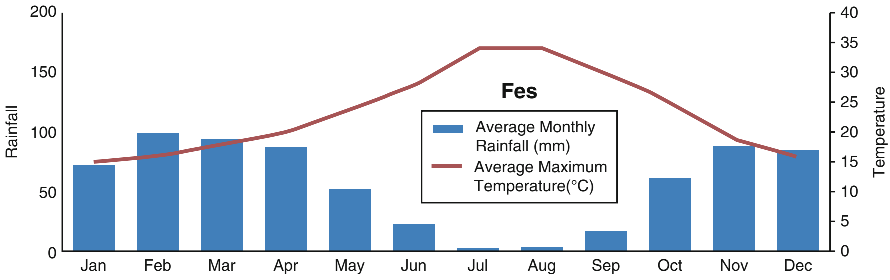

Fig. 5.2 Average monthly rainfall and temperature of Fez (lat. 34° N and long. 5° W)

Plateau, the Prerif zone and the Eastern part of the Rif mountain range. This large spatial extension translates also into a large diversity of winter temperature subtypes;

- *Subhumid*, with annual rainfall ranging from 600 to 800 mm, encountered within the mountain ranges of the Rif, the Middle Atlas, the High Atlas and on localised coastal area (Western Mamora cork oak forest). As in the previous type, the winter subdivisions are also diverse;
- *Humid*, with annual rainfall greater than 800 mm within the Rif and the middle Atlas mountains.

Rainfall is variable within seasons and between years. It occurs mostly in autumn (October–November), winter (December) and spring (March–April) as shown for Fez (Fig. 5.2) Mean annual rainfall (Fig. 5.3) ranges from less than 100 mm (Saharan bioclimate), to 1,200 mm (humid bioclimate).

Extreme temperatures are attenuated in the coastal areas along the Atlantic Ocean and the Mediterranean Sea, translating into bioclimate sub-types of warm and temperate winters. By contrast, in the inland, the temperatures are more extreme and winters can be quite cold (translating into bioclimate sub-types of temperate to cold winters) and the summers very hot. In the mountain ranges temperatures can drop to 0 °F and highest mountain peaks in both the Atlas and Rif mountain ranges are snow capped throughout most of the year.

Drought is the most important and dramatic manifestation of such variability. The country witnessed the longest drought episode in its recent history (1979–1984, most of the 1990s) causing impacts on agricultural production, on farm economics and sustainability, on systems of production (for example, more concentrates are being incorporated into livestock feeding), and on natural resources and environment (acceleration of degradation and resource depletion).

Over the last century there has been a decrease in rainfall throughout the Mediterranean region. In summer, rainfall is now 20 % less than at the end of the nineteenth century. In Tangiers, rainfall has dropped by 100 mm in 40 years and also at Ifrane, in the Moyen-Atlas Mountains. Studies show that a reduction of 100 mm i.e. 1 mm/year has taken place in many countries in the Mediterranean Basin. Since the beginning of the twentieth century, Morocco had balanced phases of rainy and

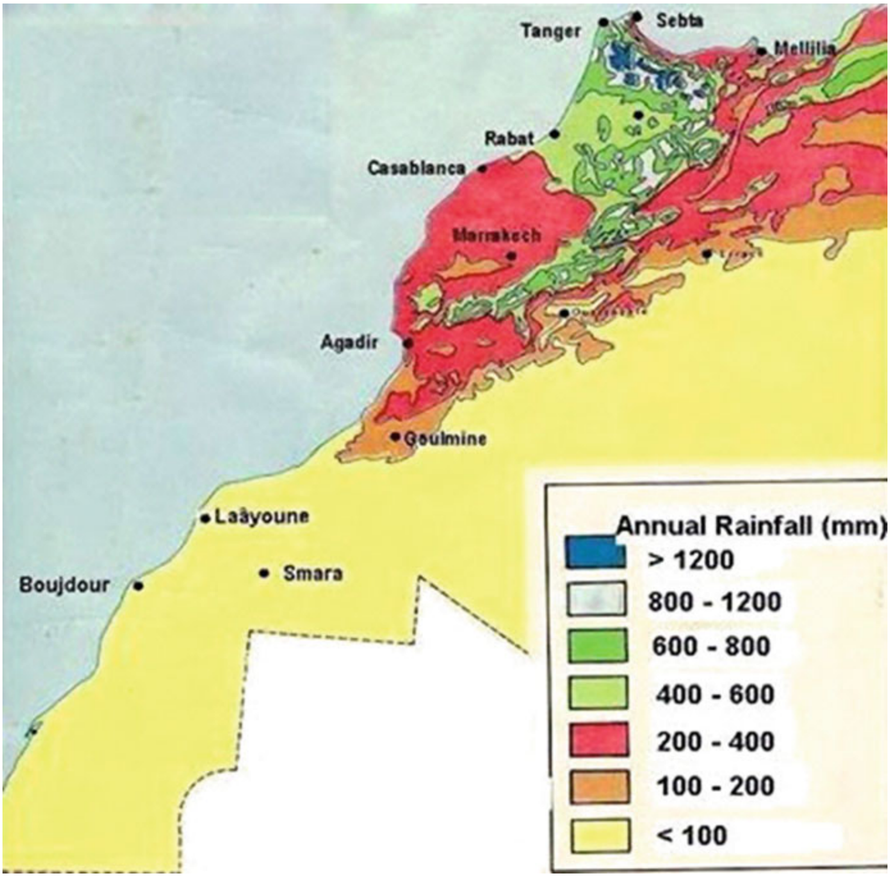

Fig. 5.3 Rainfall map showing that rainfall is low (100 mm p.a.) in most inland of Morocco

drought years. This balance seems to have broken since 1975, as the number of dry years has a tendency to exceed the humid ones. The 1980–1984 drought in Morocco was perhaps the most severe in the country over a period of 1,000 years! (Chbouki et al. 1995). A high mortality of trees was recorded that exacerbated the on-going death of trees brought about from excessive lopping of branches etc. feed livestock and provide fuel wood (see below).

3 Land Area, Arable and Pastoral Areas

Land classification in Morocco shows that 78 % of the area (56 Mha) is in desert and dry zones (annual average precipitation <250 mm/year), 15 % (10 Mha) in the semi arid zone (250–500 mm rainfall per annum) and 7 % in the sub-humid to humid

Table 5.1 Land use in Morocco

Arable and permanent crops	Area (million ha [Mha])
Forests	9.2
Alfa steppe	5.8
Range[a]	3.2
Total	52.885
	71.085

[a]Including low productivity Saharan steppes, rocky sites and areas occupied by infrastructures as they have not been estimated separately

zones (>500 mm rain per year). Arable land and permanent crops represent 12 % (9.2 Mha) of the land area, of which 1.2 Mha are irrigated, 12.5 % (5.8 Mha) is forest, and 52.9 Mha are rangelands and unproductive lands (Table 5.1).

4 Causes of Desertification in Morocco

4.1 Climatic Factors

Like the other countries south of the Mediterranean, Morocco has suffered from a negative trend in rainfall over the last few decades. In 50 years, precipitation has dropped from an annual average of 600 to 300 mm, with more and more successive dry years (1979–1984, 1990–1994, 1998–2001). During these periods, cropping in the rain-fed fields was of low productivity or crops failed and temporary food shortages occurred in the most disadvantaged parts of the country. Arable lands underwent accelerated degradation and destruction as the desertification process in the marginal lands gained momentum. In an effort to save their cattle, livestock producers invaded the forests and cut off the leafy branches to feed their animals. Is this apparent increase in droughts due to global warming or because the anticyclone from the Azores lasts longer and longer in Morocco during the winter, as witnessed in 1999 and 2000? If the tendency for more years to be hot and dry were to continue, it would have a substantial impact on the mountainous environment in Morocco; in particular the snows would melt sooner or winter snows would be replaced by rain. Both scenarios would entail a fundamental change in the regime of the waterways and have serious implications for the irrigation areas.

4.2 Human Factors

Although land degradation in these environments is partly caused by natural factors, the accelerated erosion rates are mostly human induced. Overgrazing is the most important cause of soil degradation in the eastern regions of Morocco, the Souss, the Pre-Sahara and the Sahara and approximately 8.3 Mha of rangelands are heavily degraded (Ouassou et al. 2006). The land in these regions is collectively used by local tribes and communities. Land use conflicts over access to grazing areas and water are major contributors to continual and often intensive land degradation. In the eastern region, feed subsidies for instance discourage the reduction of livestock pressure on collective rangeland. Higher prices encourage farmers to grow cereals, especially bread wheat, in steeply sloped plots. These government support policies combined to other environmental problems contributed also to soil erosion.

4.2.1 Encroachment of Traditional Rangeland for Crop Production

The disempowerment of traditional institutions has led to the disruption of management of rangelands. Transhumance has practically disappeared. Settling within rangelands has become the rule, and cultivation and privatization of the rangeland is expanding. And what remains of the original rangeland is exposed to fierce overexploitation. Rangeland rehabilitation, therefore, is a high priority for the Moroccan government, which has initiated activities aimed at halting degradation, increasing farmers' income, and stemming the rural exodus. Whilst livestock remains the main source of income, but that the pastoral system has evolved during the last decades a number of other things have occurred:

- The ancestral grazing practices, based on tribal organization and using large areas for grazing, are disappearing and rangeland is degrading at a quicker pace.
- The system is evolving towards an agro-pastoral one, characterized by the intensification of livestock production.
- Pastoral cooperatives are replacing the traditional mode of organization based on tribes.
- There is less transhumance. The best sites are cleared for cultivation.
- Pastoralists with small flocks are more sedentary and, therefore, contribute to rangeland degradation.
- More farmers are raising the Ouled Djellal breed of sheep.
- The contribution of concentrate to livestock feeding is increasing.
- The rural exodus is increasing due to a decline in livestock productivity and the high cost of feed concentrates.

The Moroccan forests are a precious and priceless heritage. They partly cover the Atlantic and Mediterranean slopes of the Moroccan mountain ranges; in the High Atlas, forestlands stretch from the *dir* to the center of the range. This heritage, however, is in great danger. For nearly a century, the forests have been subjected to increasing pressure, first from the forestry services of the French Protectorate, and during the last few decades as a result of the demographic explosion. The causes of this degradation are connected to management errors, uncontrolled exploitation, and the vagaries of the climate.

Soils with relatively low organic matter contents (<2 %) are directly impacted by the serious erosion processes which can exceed 20 tons ha^{-1} $year^{-1}$ (Merzouk 1988; AGR/DAF 2001). It is estimated by World Bank in 2003 that the total annual cost of erosion from agriculture in Morocco was about 0.41 % of its GDP.

4.2.2 Cutting of Forests

Clear cutting was introduced by French foresters during the Protectorate to meet lowland needs, in particular the need for industrial production of charcoal and rail sleepers. This method is still in use today. The government sells concessionary rights to professional coalers who engage in clear cutting, especially of holly oak forests, that usually grow on steep slopes. This method based on a European model is totally unsuitable for the Moroccan mountain forests. The lack of protective foliage exposes the fragile soils to the harsh climate. The ensuing erosion, in turn, inhibits the process of stump shoot regrowth and regeneration of the holly oaks.

For agricultural purposes thousands of ha has being cleared each year in the Rif mountains. The main species cultured is the *Cannabis sativa* L. Increased land pressure combined with a lack of economic development in the region has led to two distinct geographical expansions of cultivation – first, at the expense of forested areas, with thousands of hectares of forest being burned every year to clear new areas for cannabis production; and also in the valley bottoms where better soils and better access to water are available.

Furthermore, this practice deprives the local population of a vital and sizeable amount of dead wood. Since time immemorial, mountain people have taken the wood they needed for their daily lives from the forests. Unauthorized cutting was relatively limited for many centuries, but has increased during the last few decades. All the activities in daily life partly rely on wood and timber: cooking, crafts (making pottery, ironwork, furniture, but also souvenirs for tourists), and construction (roofs, doors, walls).

One custom that greatly damages the forest is cutting branches, especially in the holly oaks, to feed the smaller livestock during the difficult inter-crop season. This gradual, irrecoverable lopping of the leafy branches disturbs the vegetative metabolism of the trees and eventually results in another «dead forest», of which there are so many in the High Atlas. This method also contributes to accelerated soil erosion. The customary collection of dead wood for household use is a good illustration of the scope of the ongoing disaster in the forests. It is usually a chore for women in the Moroccan mountains and, in some places, accounts for up to 50–70 % of their daily activities. As the forests shrink and dead wood becomes scarce, women often have to spend over 10 h a day trekking dozens of kilometers in search of wood. Moreover, they have to «compensate» for the lack of dead wood by uprooting bushes (the thermal value of which is much lower), thereby increasing the risk of accelerated land degradation. In Morocco, 4,500 ha of woodlands are sacrificed to agriculture every year.

An ancient management system allowed a piece of land to be taken from the forest for cultivation, as long as it was subsequently returned to the matorral for at least 10–20 years. However, this forest fallowing phase has been eliminated in view of the need to expand agricultural lands. Furthermore, farmers secretly expand their farmlands by encroaching on the forestlands, tree by tree, which is difficult for the forestry officers to control. Together, all these actions are highly detrimental to the forests and severely diminish the country's forest heritage and its biodiversity. At the politico-economic level, reducing the woodlands jeopardizes their capacity to absorb CO_2 and will, in time, penalize Morocco on the "CO_2 market" provided for in the United Nations Framework Convention on Climate Change (UNFCCC).

4.2.3 Overgrazing

Overgrazing poses another serious problem for the Moroccan environment, e.g. in the Drâa Valley where vegetation is extremely sparse. In the five Drâa Valley palm groves, livestock figures are estimated at 186,000. The large numbers of sheep, goats, and dromedaries are too heavy a burden on a fragile ecosystem, be it the part-time rangelands far from the settlements, or the year-round rearing areas with high stocking rates, located within a radius of about 4–5 km from the douars. Degradation of the plant canopy allows the winds to carry away sand formerly held down by the vegetation, thus accelerating the process of desertification that is already well underway.

5 Efforts to Combat Desertification and Land Degradation in Morocco

5.1 Past and On-going Activities

Morocco ratified the UNCCD in 1996, adopted its National Program to Combat Desertification in June 2001, and established an institutional framework for its implementation. The NAP complements existing sector programs, supports their implementation and promotes an integrated drylands development approach to enhance local livelihoods. Areas of intervention of the NAP include: (1) Promotion of an enabling environment for UNCCD implementation at the policy, legislative and institutional levels; (2) Building the capacity of relevant actors at the national and local levels for drylands development; and (3) Implementation of integrated programs addressing poverty alleviation, local governance and natural resource management. NAP priorities have been effectively integrated into national development planning and budgeting frameworks, leading to their effective implementation.

Morocco finalized a National Action Program (NAP) of Combating Desertification (CD) which constitutes an important stage in the process of its commitments within the UNCCD but there is still a lack of funding or the necessary capacity in terms of personnel and equipment to fully implement the measures outlined. Government commitment to the incorporation of the NAP into the national development strategy is still some way off. Despite this, Morocco is credited by UNCCD as adopting an "integrated and comprehensive" approach in the fight against desertification and land degradation. With assistance from The Global Mechanism (GM) strengthen the national capacities to establish a development partnership and resource mobilization strategy for the NAP. The strategy focuses on:

- building the resource mobilization capacity of NAP stakeholders;
- strengthening consultations with development partners in financing priority NAP projects.

The strategy, supported by UNDP and Germany through GTZ, has allowed Morocco to integrate the combating of land degradation into national planning and sectoral investment frameworks, as well as into the priorities of several development partners. These partners include Spain that has made combating desertification a priority for its cooperation with Morocco, along with Japan, Belgium, the World Bank, the European Commission and the International Fund for Agricultural Development (IFAD), which have responded positively to the strategy by cooperating in the framework of NAP implementation. Together with IFAD and the United Nations Industrial Development Organization (UNIDO), the GM has facilitated access to Global Environment Facility (GEF) resources by financing the design of a GEF/PDF-B project that raised USD 6 million for Morocco, complementing an integrated development project to combat desertification and reduce poverty in the east of the country totalling USD 18.8 million. Through the HCEFLCD and the Ministry of Agriculture, Morocco allocates 500 million dirham a year to combating desertification and 200 million dirham to rural development, totalling the equivalent of nearly USD 100 million a year. Table 5.2 is a summary of some donor-sponsored programs.

GM-HCEFLCD cooperation has already brought positive results. In recent years, the HCEFLCD and other national stakeholders (in agriculture, water resources and the environment) have designed 53 projects based on the four priority pillars of the NAP:

- Pillar 1: support to combating desertification;
- Pillar 2: support to income-generating initiatives;
- Pillar 3: activities to fight desertification and mitigate the effects of drought; and
- Pillar 4: knowledge building, monitoring and evaluation activities.

At the civil society level, the GM has financed Environment and Development in the Third World (ENDA Maghreb) to design a plan of action to combat desertification for Moroccan non-governmental organizations (NGOs), subsequently integrated into UNCCD/NAP priority projects. Twelve projects based on interlinking and integrating the two themes of desertification and decentralization have been identified and were presented to partners during a national workshop in February 2007. Budget Allocation for follow-up activities has been seriously curtailed and there is more dependence on external (mainly donor) funding.

Table 5.2 Donor-supported projects for combating desertification in Morocco

Title of the Project	Countries	Donor/Program	Comments
Système de gestion d'information scientifique dans la région de Sahel-Doukkala, Maroc	Morocco	LIFE Third Countries	LIFE
Aménagement hydro-agricole du périmètre de Sahla au Nord de la province de Taounate	Morocco	MEDA I Bilateral	EC Delegation
Appui au développement rural intégré	Morocco	MEDA I Bilateral	EC Delegation
Le développement rural participatif dans le Moyen Atlas central	Morocco	MEDA II Bilateral	EC Delegation
Appui à la situation de l'emploi de la femme rurale et gestion durable de l'arganerie	Morocco	MEDA II Bilateral	EC Delegation
Développement participatif des zones forestières de la province de Chefchaouen	Morocco	MEDA I Bilateral	EC Delegation
Forestry Development Project	Morocco		World Bank
Irrigation based Community Development	Morocco	World Bank	World Bank
Emergency Drought Recovery Project	Morocco	World Bank	World Bank
Implementation of pilot systems to monitor the desertification in two countries of the southern coast of the Mediterranean: Tunisia and Morocco	Tunisia, Morocco	LIFE Third Countries	LIFE
Participatory Control of Desertification and Poverty Reduction in the Arid and Semi-Arid High Plateau Ecosystems of Eastern Morocco	Morocco	GEF OP15 Land degradation	IFAD

Overall, negotiations between Morocco and its cooperation partners have generated a total of 1.8 billion dirham (about USD 225 million) to finance integrated projects to combat desertification. Combating desertification is central to not only climate change issues, biodiversity preservation, and water and soil conservation, but also to food security and combating poverty. In Morocco, 93 % of land is affected by desertification processes resulting from unpredictable rainfall, which has tended to decline with unequal and irregular distribution for nearly a century.

The situation is exacerbated by human pressures: an imbalance between the demand for and scarce supply of water; vulnerability and overexploitation of forest ecosystems, rangelands, and already limited soil resources. The per capita useable agricultural area (UAA) is in continuous decline. The cost of natural resource degradation in the forest, agricultural and rangeland sectors and following the silting up of dams is calculated to be 2.9 billion *dirhams* a year. The NAP must therefore translate into effective measures and actions on the ground. This is the aim of the GM's support to the design of a national resource mobilization strategy based on ensuring coherence between internal and external financing and the integrated application of a range of international instruments for sustainable land management (SLM) and combating desertification.

Even serious matters like deforestation that threatens livelihoods, water storage for irrigation and soil productivity has not been given the support that it requires. In Morocco, reforestation started in 1949 and currently accounts for a total of 767,000 ha of woodlands. The evaluation made at the end of 2000 shows that a net 530,000 ha had actually been reforested, i.e. about 10,000 ha per year. The much higher objective of 22,000 ha per year has only been achieved one single time since 1970. Management and oversight of the precious forests and rangelands is restricted to about 4 Mha of forest land and about 2.3 Mha of rangelands.

Efforts have been made to improve grazing management and apply more scientific principles to rangeland monitoring and condition assessment.

During the period 1980–1990 efforts to were concentrated on:

- the establishment of the rangeland service in the Ministry of Agriculture;
- the training of engineers specialized in range management;
- the delimitation of 11 range improvement areas;
- the organization of the stockbreeders in pastoral co-operatives;
- the launching of the "ley farming" program in the dryland zones (use of annual medics and clovers on traditional fallow "*bour*");
- the planting of fodder shrubs on 17,000 ha; mainly *Atriplex nummularia* and *Opuntia inermis*
- the installation of protected areas on 28,000 ha in the High Atlas and Tafrata zones;
- the establishment of the El Jadida seed production center (Centre de Production des Semences Pastorales);
- the execution of several studies relating to rangeland use;
- the execution of a large program related to the basic infrastructures concerning water, wells, pastoral roads and dipping tanks.

There are opportunities for improvement of fodder resources that can relieve that pressure on the grazing lands and also allow a higher turn-off of livestock for slaughter and at a younger age.

In order to overcome some of the limitations stated above, the Ministry of Agriculture has developed a strategy for range development. The main objectives of this strategy are to:

- create an economical environment compatible with the objective above, allowing the adhesion of the producers and the sustainability of animal production systems;

- satisfy the demand for red meat by the year 2020;
- create a facilitating economic environment for the long term participation of producers and for the sustainability of animal production systems;
- organize stakeholders and facilitate the modernization of pastoral activity;
- conserve natural resources and improve livestock productivity.

The following actions are being taken at different levels in order to achieve the stated objectives:

5.2 *Policies and Legislation: Review and Update*

- Strengthen management capacity to make better economic use of investments and for the integration of livestock into farming systems. This would be a prerequisite to improving livestock productivity on rangelands;
- Improve marketing channels to benefit herders, particularly the large number of small-scale operators, by providing them access to agricultural credit and markets.

5.2.1 Land Tenure Reform

- Promote community-based organization(s) to ensure active and continued participation of all members of the community in the management of grazing land, to establish and/or clarify by delimitation and registration the status of collective pastoral lands, and especially to put restrictions on land sub-division and shifting agriculture;
- It must be made clear that range management is not simply a technical issue because it also translates land policy into economic use/conservation of basic resources, and the type of development provided to producers without adversely affecting the interest of their heirs or of the nation;
- The selection of interlocutors is crucial to the success of the endeavor, given the nature of the activities to be undertaken. Consequently the beneficiaries must all have similar needs and aspirations in order to minimize conflict. The group leaders must also be clearly identified.

5.2.2 Conservation and Sustainability

One of the main objectives of the strategy for rangeland development relates to the sustainable use of the resources. Protection of the environment is central to this strategy (combating desertification, conservation of biodiversity and agro-biodiversity). Each year, 100 million tons of soil is removed. Several soil conservation technologies have been developed in Morocco and are available for large diffusion but in many cases these technologies have not been permanently adopted.

These technologies deal mainly with soil and water conservation techniques and water harvesting. The Taourirt-Taforalet Rural Development Project (PRDTT) financed by the International Fund for Agricultural Development (IFAD) contributed financially to the introduction of these new practices at some farms in the eastern region in order to encourage large dissemination. However, only a small percentage of farmers (7 %) adopted the new technologies without the project support (Shideed et al. 2005). It seems that a large-scale dissemination of these new practices requires some financial incentives that must be sufficiently high to stimulate farmers to adopt the technologies.

5.2.3 Range Rehabilitation

There is a plan, to be undertaken on 20 Mha over 20 years, to survey the use of pastoral resources. Having these data will strengthen the base for initiating rangeland management initiatives and the registration of communal lands in order to clarify the status of the area to be managed. At the same time, undertaking range improvement and rehabilitation, and taking action, both in time and space, will allow for the generation of credible production and conservation statistics. These actions will involve the rehabilitation of severely degraded rangelands (8.3 Mha over 20 years at a rate of 200,000 ha/year), the improvement of the productivity of rangelands with high potential (50,000 ha/year over 20 years) and the improvement and management of rangelands that are presently still considered to be in satisfactory condition.

5.2.4 Collecting Native Rangeland Species

The rangelands of north-eastern Morocco are home to a diversity of rangeland species. They are an invaluable resource to rehabilitate fragile, dry environments. Due to over-exploitation of these native plants and their habitat, however, many are endangered and some are close to extinction. To this end, ICARDA and national research institutions undertook a mission to assess rangeland biodiversity and collect native rangeland species. The collection covered 43 sites over an area of 2,200 km and rainfall zones of 180–500 mm. Samples were collected at intervals of 10–15 km along the collection route. Over 385 accessions of 60 species were collected. *Stipa* spp. were most frequent (51 accessions of four species). *Artemisia* spp. were also frequent. Other species collected included *Heliantheum* spp., *Herniaria* spp., *Paronychia argentea, Schismus barbatus*, and *Thymus* spp. Vetch (*Vicia*) and medic (*Medicago*) species were found in areas protected from grazing (Fig. 5.4).

Fig. 5.4 Collection of seeds from rangeland plants, including trees and shrubs in Eastern Morocco

5.2.5 Grazing Land Improvement

Results achieved during the phase 1969–1980 made it possible to draw the main lines for rangeland development. These, which are supported by the organization of beneficiaries, the range studies and the rational exploitation of the rangeland, have formed the basis for development of several range projects such the Middle Atlas project, the FAO-UNDP project and the USAID Range improvement project under which capacity building has been reinforced. Activities included characterization and mapping of rangelands; critical appraisal of past and ongoing rangeland development projects; testing methods of rangeland rehabilitation; community-level marginal land rehabilitation; and community seed production of range species.

5.2.6 Monitoring and Assessment of Land Cover Change

The integration of satellite imagery and ancillary data with statistical modelling provides access to updated information for the mapping of rangeland facies, statistical analysis, zoning and identification of vulnerable zones. The building of a database permits the statistical and spatial analysis of data for better under-standing, management and use of rangeland resources.

The Geostat-Maroc project resulted in the building of a rangeland database and a monitoring system based on a GIS. The database can be regularly updated (every 2–5 years for example) according to the degree of environmental pressures on the natural habitat. This methodology can produce a statistical inventory of national rangeland cover with an accuracy as high as 90 %. It can be easily applied in other countries and regions where rangeland resources are important. This project was carried out by the Royal Centre of Spatial Remote Sensing (CRTS), the Department of Livestock and the IAV Hassan II (MAMVA), in collaboration with the National Centre for Spatial Studies (CNES), ENSAT, INSEE and Scot-Conseil of France.

5.2.7 Advocacy, Partnership Building and Resource Mobilization for Climate-Resilient Development in the Oases of Southern Morocco

This program focuses on the drier regions of the south and south-east. Support will be channeled within the framework of the project "Sustainable Territorial Development of Southern Provinces". This project – implemented by "Agence du Sud" in collaboration with regional and local authorities – acts as a framework for regional/local development and a catalyst for investment. The Program will support project efforts to mobilize partners and resources to promote climate resilient development in the southern provinces. Both climate change and accelerated land degradation are major threat to the oases communities There is need to:

- Raise awareness on the impacts of climate change on the oases of Morocco;
- Mobilize partners and resources to promote climate-resilient development in the oases of Morocco.

6 Integration of Forages into Farming Systems

The major challenge to livestock production is the dwindling feed sources. The increase in small ruminant numbers is subjecting the already degraded rangelands to further degradation, and farmers are facing an acute shortage of feed. To support resource-poor farmers, therefore, there is an urgent need to both regenerate the rangelands and provide alternative sources of low-cost feed, such as cactus and feed blocks made from agricultural by-products (Fig. 5.5). Spineless cactus or shrub (*Atriplex halimus*) alone or intercropped with barley, vetch, oats, or other forage crops can improve the supply and quality of feed resources and prevent soil erosion, especially on hillsides outcome of alley cropping was that due to the increase in feed supply, farmers increased flock size. The calculations suggest that alley cropping increased the number of small ruminants by 25 % among technology adopters.

6.1 Integrated Livestock/Rangeland/Crop Production Systems

A range of technologies have been developed to integrate crop-livestock-rangeland production systems. These include:

- Barley production with alley cropping of shrubs such as *Atriplex* spp.
- On-farm feed production
- Feed blocks produced from agro-industrial by-products
- Spineless cactus and fodder shrubs
- Flock management
- Natural pasture enhancement and rangeland management

Fig. 5.5 Planting of long lived drought-resistant hardy perennials into rangeland can provide a valuable protein supplement during the dry season and a drought reserve. *Atriplex* spp. perform well (Photo B.E. Norton)

- Increase animal productivity: animal health and nutrition, better use of genetic resources including wild breeds, and better access to markets and by-products
- Improvement of rangelands: rehabilitate degraded rangelands, improve grazing management.

First, the development of the cactus/*Atriplex* alley cropping in the WANA region has encouraged the governments of Morocco and Tunisia to invest in agriculture in dry areas. By increasing and stabilizing fodder reserves, cactus/*Atriplex* alley cropping can help mitigate drought. The technology is therefore an effective risk-hedging strategy for drylands. The benefits are expected to spur adoption by farmers in similar agro-ecological zones in Morocco, Tunisia and other countries. It is necessary to capture the holistic nature of the problem by integrating economic, environmental and social aspects.

The most important action to integrate forages into the farming systems was the ley farming operation. Other actions include promotion of the new feed production techniques such as fodder conservation, valorization of straw, and utilization of agro-industry by-products.

Development of productive and sustainable production systems based on small ruminants, through the integration of feed and livestock production, both within and across arable and rangeland production systems is a high priority. This would improve the incomes and welfare of farmers and pastoralists in the low-rainfall areas of Morocco, while meeting national demands for small ruminant products and conserving the natural resource base.

Several collaborative research and development projects ('Multipurpose Fodder shrubs and Trees', 'Sustainable Management of the Agro-Pastoral Resource Base in the Oujda Region', the 'Mashreq/Maghreb' project, the 'Taourirt-Tafoghalt' project, and the 'Pastoral and Herding Development' project) are operating in the region. ICARDA and the Moroccan national program are key participants. A common feature of these projects is the use of a participatory approach involving all stakeholders concerned with sustainable development of agropastoral resources. Involvement of pastoral communities within the 'Sustainable Management of the Agro-Pastoral Resource Base in the Oujda Region' project, supported by the Swiss government, is described below to illustrate this participatory approach.

Due to human and animal population growth, cropping has expanded into low rainfall areas and into very fragile environments to the detriment of rangeland, resulting in increased feed deficit and soil erosion. To reverse the situation, ICARDA and its Moroccan partners are testing the suitability of shrubs as an intercrop (alley cropping) with barley and other common crops, such as oats, and mixtures of barley and fodder pea, and barley and vetch.

The ley farming operation was launched in 1986 aiming at the integration of sheep and cereal production by cultivating the 1.6–2.6 Mha that have been in fallow each year. Despite the real advantages that this operation represents in the semi-arid regions of Morocco, the substitution of the rotation cereal-annual medics or cereal-subterranean clover was only done on about 5,200 ha/year. The main reason for the limited adoption of this system is related to the size of the farms. In fact, most of the farms are very small and scattered which makes movement of the herd and grazing difficult.

Alley cropping where an annual crop is planted between rows of the perennial shrub *Atriplex* provide a stable and productive system that benefits the integrated livestock-cropping system.

On-station and on-farm testing suggests that alley cropping with *Atriplex* (saltbush) could greatly increase crop and animal production, and at the same time help to protect fragile soils from wind and water erosion.

Total biomass and grain yield were higher in alley cropped systems. Energy and crude protein yields also increased by 11–93 % and 16–196 %, respectively. Alley cropping increased land equivalent ratios from 1 (barley or weedy fallow) to 1.20–1.46, suggesting that this technology will be particularly useful in areas where farm size is small. (A land-equivalent ratio of more than one indicates that growing an intercrop gives higher total output per unit area than a single crop). The adoption of this technology is taking off. Indeed, a total of 6,000 ha of alley cropping systems have already been established on private farms within the Taourirt-Tafoghalt project. This was a result of collaboration between different research and development projects, such as the CGIAR System-wide Livestock Program's Multipurpose Fodder Shrubs and Trees project led by ICARDA, ICARDA's Mashreq Maghreb project, and the Taourirt-Tafoghalt project. A further 8,000 ha are to be alley cropped in the coming years (Fig. 5.6).

Fig. 5.6 A photograph of *Atriplex* in an alley cropping system with barley as the cereal crop (Photo B.E. Norton)

7 Conclusions

Morocco faces many challenges as populations rise, the pressure on land increases and more and more marginal rangeland is converted for cropping (often with disastrous consequences) and the impact of climate change is more severe.

A number of new farming systems have been developed, better remediation measures have been devised and the adoption of new ideas is progressing rapidly, especially for alley cropping.

Acknowledgements A synthesis of this nature necessarily involves drawing upon the plethora of sources some published in less accessible reports that have been prepared under the auspices of the government of Morocco, by the UN system and by the donor community including NGOs. The author is grateful to all those people whose materials formed the fabric of this chapter and the government of China for the opportunity to attend and participate in the Desert technology training course in Wu Wei in 2006. Gratitude is expressed for use of the photographs of Dr. B.E. Norton.

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Chapter 6
Egypt: Land Degradation Issues with Special Reference to the Impact of Climate Change

Kh. Darwish, M. Safaa, A. Momou, and S.A. Saleh

Synopsis A general survey of the land degradation issues that affect Egypt from the arid regions of the south and east to the coastal zones along the Mediterranean and Red Sea coast. Land Degradation in the agricultural zone east of the Nile Delta is examined. The potential effects of climate change on the coastal zone of Egypt provides the principal focus. Mitigation and adaptation measures are outlined.

Key Points

- Only 4 % of Egypt is arable, most of it along the floodplain of the Nile but two other important zones exist. The area east of the Nile Delta and the El Fayoum Depression. Land degradation is a risk to the limited areas of cultivated land. The complex ecosystem of the Nile, which has nurtured civilizations for millennia, has already been deeply affected in the last 60 years by the construction of the High Dam in the southern city of Aswan. The giant project managed to regulate the often devastating effect of the Nile's yearly floods, but it also deprived lands of crucial nutrients and minerals.
- The dominant feature of Egypt's Northern Coastal Zone is the low lying delta of the River Nile, with its large cities, industry, agriculture and tourism. The Delta and the narrow valley of the Nile comprise 5.5 % of the area of Egypt but over 95 % of its people of which 25 % live in the Low Elevation Coastal Zone (LECZ) areas. In this context, the Nile Delta and Mediterranean Coast includes 30–40 % of Egypt's agricultural production, half of Egypt's industrial production, mainly in Alexandria, Damietta and Port Said.
- Due to the concentration of much of Egypt's infrastructure and development along the low coastal lands and the reliance on the Nile delta for prime agricultural land, coastal inundation or saline intrusion caused by anthropogenic climate change induced sea-level rise will have a direct and critical impact on

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Egypt's entire economy. Observations confirm that sea-levels are already rising in the Nile delta due to a combination of factors including coastal subduction and reduced sediment loads due to the construction of the High Aswan Dam upstream. Land subsidence is currently estimated at 1–5 mm/year.

- The coastal zone of Egypt extends for more than 3,000 km and is the home for more than 40 % of the population. Most of these people live in and around a number of very important and highly populated industrial and commercial cities: Alexandria, Port Said, Damietta, Rosetta and Suez. The coastal zone of Egypt suffers from a number of serious problems, including a high rate of population growth, land subsidence, excessive erosion rates, water logging, salt water intrusion, soil salinization, ecosystem pollution and degradation, and lack of appropriate institutional management systems. Realizing the importance of this zone, the Egyptian government has already taken steps towards reducing the impact of these problems.
- Egypt is potentially one of the countries most at risk from the effects of climate change. It is located in an arid – to semi-arid zone. Its only source of water, the River Nile, provides more than 95 % of all water available to the country. The source of this water lies far to the south, from rainfall on Ethiopian hills (86 %) and equatorial lakes (14 %). Most of the population of Egypt (over 60 million people in total) is associated with the agricultural sector which constitutes 20 % of gross national products and consumes about 80 % of the water budget.
- Egypt is taking the issue of climate change seriously. The Nile Delta and coastal zones are prone to flooding due, in part, to rising sea levels. Climate change will potentially negatively affect agricultural productivity as a result of increased average temperature. Human health is also at risk due to climate change. The increased temperatures might lead to the outspread of vector-borne diseases. Coral reefs are one of Egypt's natural resources that climate change adversely affects. Egypt seeks the help and support of the international community to mitigate the impact of climate change.

Keywords Sea level rise • Climate change • Tourism • Population pressure • Irrigation • Land reclamation • Desert research Center • Wind power • Nile River • Nile Delta • Sea water incursion • Aswan dam • Lake Nasser • Oasis • Temperature rise • Rangelands • Biodiversity • Desertification • Salinity • Sodicity • Sudan • Libya • Israel • Mediterranean Sea • Red Sea • Gulf of Suez • Gulf of Aqaba • El Fayoum • Sinai Peninsular • Cairo • Alexandria • Rosetta • Lake Moeris • Coastline

1 Geography of Egypt

Egypt covers an area of approximately 1,001,450 km^2 and is bordered by Israel, the Gaza Strip, in the north-east, the Red Sea in the East; Sudan in the south; Libya in the west; and the Mediterranean sea coast in the north. Egypt is the third most populous country in Africa, the 30th largest country in the world and the most populous in the Middle East. The Red Sea, the Gulf of Suez, and the Gulf of Aqaba to the east endow the country with a coastline stretching over 3,000 km in all. The majority of the 80 million people live on, or near, the banks of the Nile River. Only 5.5 % of the total land area is actually used by the population,– the area that borders the Nile River as well as a few oases, the other 94.55 % being uninhabitable desert. The Nile river virtually bisects the desert and the area to west is known as the Western desert or the Libyan desert, with the area to the east, as far as the Red Sea being called the Eastern desert. The Libyan Desert is characterized by massive sand dunes and eight great depressions. The desert itself is sparsely inhabited with relatively small population centers growing up around oases, notably the El Fayoum (see below).

The highest elevations in Egypt are in the southern part of the country. The southern regions of the Sinai Peninsula are also mountainous. Temperatures in most of Egypt range from 26–30 °C in summer and from 12–20 °C in winter. The Mediterranean coast enjoys a cooler temperature in comparison to the rest of the country. Frequent dust storms called ‘Khamaseen’ blow south–north in summers. Rainfall is scanty and unpredictable. The higher elevations in the Sinai Peninsula face snowfall occasionally in winters. Most of Egypt is an arid desert with little or no vegetation. The Nile, the longest river in the world, flowing from the south to the north, cuts through this desert plateau and renders the county habitable. In fact, the Nile endows its delta with fertility unheard of in desert regions. The river Nile is fed by the White Nile, the Blue Nile and the Atbara rivers of central Africa. The Nile enters Egypt near Wadi Halfa in Sudan.

Lake Nasser to the south of Egypt is a man-made reservoir resulting from the construction of the Aswan Dam across the Nile. The Aswan Low Dam was constructed at the First Cataract of the Nile in 1902. The High Dam was constructed between 1960 and 1970. The region extending from the Aswan Dam to the city of Cairo is referred to as the Nile Valley. The region further up north is the Nile Delta (see below). Low-lying, flat, and rich in silt deposits, the Nile Delta’s agricultural products support the entire country. The Nile is said to have had seven distributaries creating the fan-shaped valley. At present only two of these distributaries, the Damietta and the Rosetta carry the Nile waters to the Mediterranean Sea.

2 Agro-ecological Zones and Land Use

Egypt, with land extending over one million square kilometers under arid and hyper-arid climatic conditions, is endowed with varied agro-ecological zones with varied and specific attributes of resource base, climatic features, terrain and geomorphic characteristics, land use patterns and socio-economic implications (Fig. 6.1).

The zones could be identified as follows:

1. North Coastal Belts: Including North West coastal areas and Northern areas of Sinai.

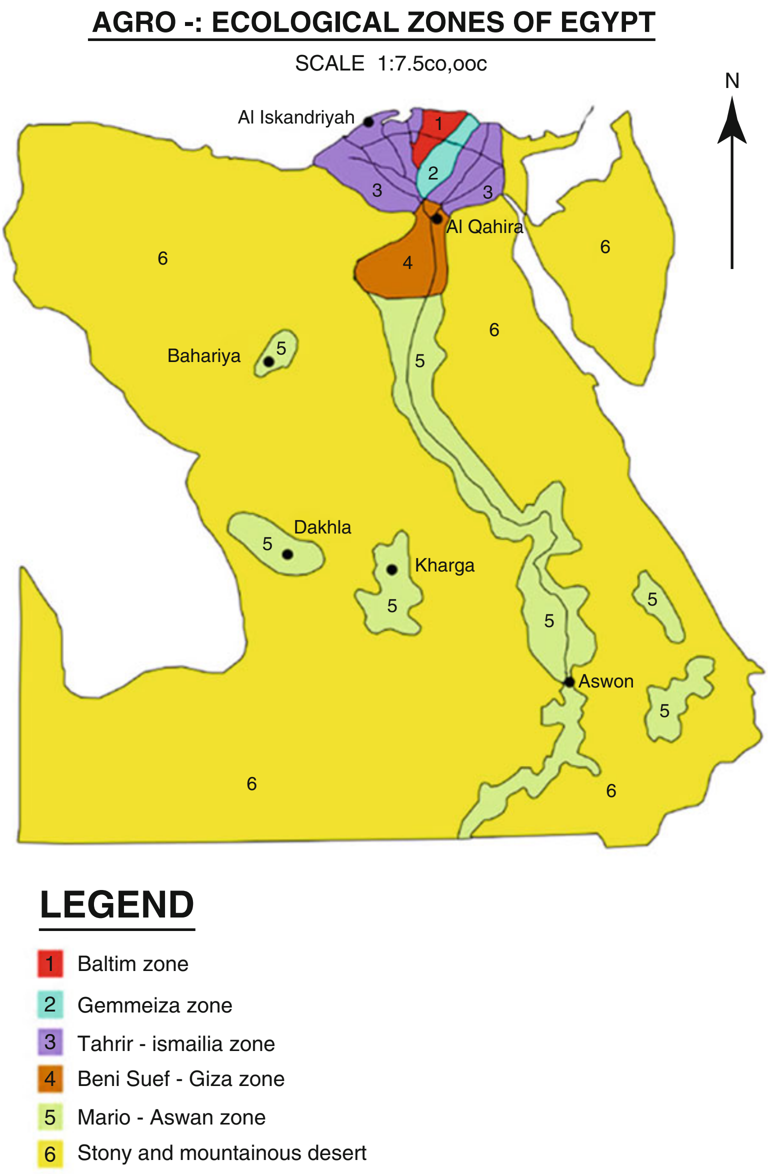

Fig. 6.1 Agro-ecological zones in Egypt

2. The Nile Valley: Encompassing the fertile alluvial land of Upper Egypt, the Delta and the reclaimed desert areas in the fringes of the old Nile valley.
3. The Oases and Southern Remote Desert Areas: Including Uwienate, Toshki and Darb El-Arbien Areas and Oases of the Western Desert.

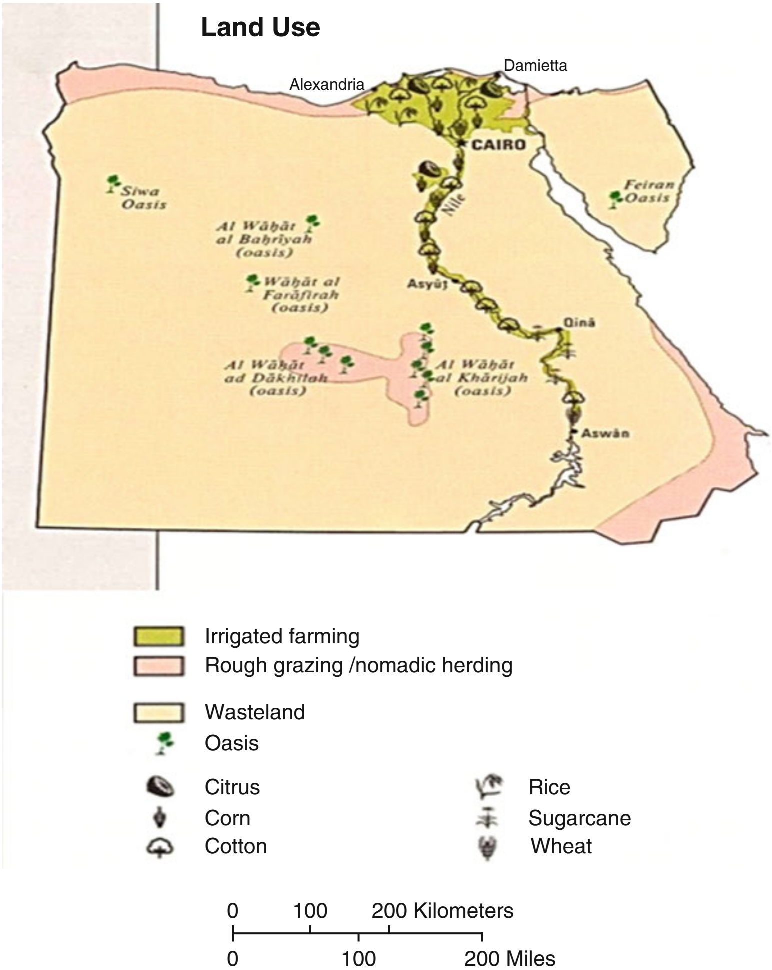

Fig. 6.2 Land use map of Egypt

4. The Desert Inland: Including the plateau and dry valleys of Sinai and elevated areas in the Southern Eastern Desert (Fig. 6.2).

3 Land Degradation in Agricultural Zones

Land degradation is a risk to the limited areas of cultivated land. The complex ecosystem of the Nile, which has nurtured civilizations for millennia, has already been deeply affected in the last 60 years by the construction of the High Dam in the

Fig. 6.3 Satellite view of Nile Delta and part of the Mediterranean coast

southern city of Aswan. The giant project managed to regulate the often devastating effect of the Nile's yearly floods, but it also deprived lands of crucial nutrients and minerals. Only 4 % of Egypt is arable, most of it along the floodplain of the Nile but two other important zones exist. The area east of the Nile Delta and the El Fayoum Depression.

3.1 Nile Delta

The Nile Delta is low-lying, flat, and rich in silt deposits. The recognized landforms comprised; old deltaic plain, eolian plain and depression with alluvial deposits. The Nile Delta's agricultural products support the entire country. An extensive network of canals now crisscrosses the delta region and assists the flow of the waters into the agricultural fields. A number of lakes and marshes dot the Nile Delta. In the eastern part of the Nile Delta area (west of the Suez Canal) land degradation threatens the ongoing agricultural activities and prohibits further reclamation expansion (Fig. 6.3).

The Nile Delta, Egypt's bread basket since antiquity, is being turned into a salty wasteland by rising seawaters, forcing some farmers off their lands and others to import sand in a desperate bid to turn back the tide. The fertile Nile Delta provides around a third of the crops for Egypt's population of 80 million and a large part of these crops are exported providing the country with an important source of revenue.

Climatic changes (see below) have forced some Delta farmers to abandon their land, while others are trying to adapt by covering their land with beds of sand to isolate it against seawater infiltrations, and grow crops.

Land reclamation has been going on for some years but salinization, alkalization, soil compaction and water logging are the main barriers to irrigated agriculture in the area. The main causative factors of human induced land degradation types on the already established areas are; over irrigation, human intervention in natural drainage, improper time use of heavy machinery and the absence of conservation measurements. Low and moderately clay flats, gypsiferous flats, have high to very high risk in both salinization, sodification (becoming strongly alkaline) and physical degradation. The assessment of the different degradation degrees has been carried out through integrating remote sensing, GIS and GLASOD approaches (Mohamed et al. 2012). A spatial land degradation model was developed based on integration between remote sensing data, geographic information system, soil characteristics and DEM. This will be of great help and be the basis for the planners and decision makers in developing more sustainable land use plans (Ali and Shalaby 2012).

3.2 El Fayoum Depression

The El Fayoum oasis is a depression or basin in the desert immediately to the west of the Nile and south of Cairo. The extent of the basin is estimated to be between 1,270 and 1,700 km^2. The floor of the basin is irrigated by a canal from the Nile. The depression comprises lacustrine plain, alluvial–lacustrine plain, and alluvial plain representing 12.2, 53.6, and 34.2 % of the total area, respectively. Over 1,000 km^2 of the El Fayoum is irrigated. Drainage water goes to Lake Moeris – a once freshwater lake.

Land degradation puts cultivated land in El Fayoum depression at risk. Most of lacustrine and alluvial–lacustrine soils are actually degraded by salinization, sodification and waterlogging. The results from research by Ali and Abdel Kawy (2012) indicate that severe risk to chemical and physical degradation affect 54.2 and 29.2 % of the depression, respectively. Negative human impact affects 26.3 % of the area mostly in the alluvial plain. Great efforts related to the land management are required to achieve agricultural sustainability (Ali and Abdel Kawy 2012).

4 Egypt's Coastal Zones

4.1 The Setting

The dominant feature of Egypt's Northern Coastal Zone is the low lying delta of the River Nile, with its large cities, industry, agriculture and tourism. The Delta and the narrow valley of the Nile comprise 5.5 % of the area of Egypt but over 95 % of its people of which 25 % live in the Low Elevation Coastal Zone (LECZ) areas. In this context, the Nile Delta and Mediterranean Coast include 30–40 % of Egypt's agricultural production, half of Egypt's industrial production, mainly Alexandria, Damietta and Port Said. The three main Delta lagoons are Idku, Burullus and Manzala produce over 60 % Egypt's fish catch. In addition, Alexandria is known as the main summer resort in Egypt and the returns from the inbound tourism forms one of the main sources of income to the city. Approximately 15 % of Egypt's GDP is generated in these LECZ.

Due to the concentration of much of Egypt's infrastructure and development along the low coastal lands and the reliance on the Nile delta for prime agricultural land, coastal inundation or saline intrusion caused by anthropogenic climate change induced sea-level rise will have a direct and critical impact on Egypt's entire economy. Observations confirm that sea-levels are already rising in the Nile delta due to a combination of factors including coastal subduction and reduced sediment loads due to the construction of the High Aswan Dam upstream. Land subsidence is currently estimated at 1–5 mm/year. The present coastal erosion and retreat of the Delta, which are aggravated by human interventions such as reduced sediment input, groundwater extraction, and hard engineering work in coastal strip. Protecting coastal zone areas at risk from the affects of climate changes (see below) has been internationally recognized, particularly in *Agenda 21, Chapter 17*. The United Nations Convention on Climate Change (UNCCC), has urged developed and developing countries to work together to mitigate and adapt to the impacts of climate change. *Agenda 21, Chapter 40*, has also stressed the need for information for decision making concerning environmental problems and sustainable development.

4.2 Problems Faced

The coastal zone of Egypt suffers from a number of serious problems, including a high rate of population growth, land subsidence, excessive erosion rates, water logging, salt water intrusion, soil salinization, land use interference, ecosystem pollution and degradation, and lack of appropriate institutional management systems. Egypt's coastal zones constitute particularly important regions from economic, industrial, social and cultural points of view. In addition to increased tourism activities, a tremendous move towards building new industrial complexes is in progress at this time. Realizing the importance of this zone, the Egyptian government has already taken steps towards reducing the impact of these problems.

The coastal zones of Egypt extend for over 3,000 km in length along the Mediterranean Sea and Red Sea coasts. The Mediterranean shoreline is most vulnerable to sea level rise due to its relatively low elevation. The wetlands of the Nile delta constitutes about 25 % of the total area of wetlands in the Mediterranean region, and produce over 60 % of the fish catch of Egypt. The coastal zone of Egypt is therefore particularly vulnerable to the impact of sea level rise in addition to impacts on water resources, agricultural productivity and human settlements.

4.3 Sea Level Rise

Egypt's Mediterranean Coast is very vulnerable to the impacts of sea level rise (SLR). A 0.3 m SLR would be sufficient to increase flood frequency from the present estimate of one in ten year flood to ten times a year. Several studies on the vulnerability of Alexandria, the second largest city in Egypt, indicated that a 0.3 m SLR in Alexandria would inundate large parts of the city. This would result in land and property losses worth tens of billions of dollars, including damage to infrastructure, over half a million inhabitants to be relocated and approximately 70,000 lost jobs (El-Raey et al. 1999). Furthermore, with SLR exceeding 0.5 m over this century, that is predicted to result in devastating impact on Alexandria with an economic loss estimated of over US$ 35 billion including loss of 30 % of the total area and 195,000 jobs, and relocation of more than 2 million people.

Several general analyses of the potential impact of sea level rise on the Nile Delta coast have been carried out (e.g. Sestini 1989; El-Raey 1993; CRI and Delft Hydraulics 1992; Stanley and Warne 1993). As a result, areas of high vulnerability in the Nile delta and possible socio-economic impacts have been generally defined. These high-risk areas include parts of Alexandria and Behaira governorates, Port Said and Damietta governorates, and Suez governorate. In addition, several other smaller areas, such as those near Matruh and north of Lake Bardaweel, have also been identified.

Accurate, up to date information on elevation, land use and socio-economic characteristics is still needed for an integrated assessment of possible impacts. As a result, a complete quantitative, high resolution analysis and assessment has not yet been finalized. However, a pilot quantitative analysis, using a geographic information system and land use classification obtained by remote sensing over the governorate of Alexandria, has been carried out, (El-Raey et al. 1995).

Satellite images of the governorate were used by the present authors to obtain information on land use in the coastal area and were supplemented by available ground survey data. A geographic information system (GIS) was built and checked with information based on available ground data. The GIS includes data layers on land use/land cover, topography, and population density distribution over Alexandria. A scenario of sea level rise (SLR) of 0.5, 1.0, and 2.0 m, over the next century was assumed. Analysis of the GIS data for the three scenarios indicates the capability of the technique to map vulnerable areas and to quantitatively assess vulnerable sectors in each area. Table 6.1 presents gross percentage loss for each scenario of SLR.

Table 6.1 illustrates that, if no protection action is taken, the agricultural sector will be the most severely impacted (a loss of over 90 %), followed by the industrial sector (loss of 65 %), and the tourism sector (loss of 55 %) due to a SLR of 0.5 m. Estimation of the socio-economic impact due to loss of land and jobs is possible using employment statistics relevant to each sector and taking future growth rates into consideration. Results of the impact on population and loss of employment are shown in Table 6.2. It is estimated that a SLR of 0.5 m in the governorate of Alexandria alone would cause a displacement of almost 1.5 million people and the

Table 6.1 Potential loss of area, population and land use due to Sea Level Rise (*SLR*) over Alexandria Governorate, in the Nile Delta of Egypt

Attribute	SLR 0.5 m	SLR 1.0 m	SLR 2.0 m
Area	51	62	76
Population	50	64	79
Agriculture	93	95	100
Industry	65	70	90
Residential	45	50	75
Municipal services	30	50	70
Commercial areas	20	25	35
Community facility	15	20	30
Archeological sites	48	55	70

Table 6.2 Population expected to be displaced and loss of employment due to SLR in Alexandria Governorate

Year	2000 (SLR = 5 cm)	2010 (SLR = 18 cm)	2030 (SLR = 30 cm)	2050 (SLR = 50 cm)
Area at risk (km^2)	32	144	190	317
Population to be displaced	57	252	545	1,512
(a) Agriculture	0,336	1,370	3,205	8,812
(b) Tourism	1,359	5,737	12,323	33,919
(c) Industry	5,754	25,400	54,936	151,200
Total loss of employment	7,449	32,509	70,465	195,443

Table 6.3 Areas (km^2) population displaced and employment losses due to a SLR of 0.50 m in various districts of Port Said Governorate, Egypt

Losses	El Shark	El Arab	El Monakh	El Dawahy	Port Fouad	Total
Beach area	0.426	0.377	7.419	–	13.039	21.26
Urban area	0.034	0.044	0.339	–	0.046	0.46
Industry area	0.015	0.002	0.018	–	0.016	0.05
Agriculture area	0.000	0.000	0.000	–	0.000	0.000
Aquaculture area	0.000	0.000	0.000	–	0.024	0.024
Transport network (km)	10.0	7.0	3.0	–	3.0	23.0
Population (persons)	3,968	16,699	6,503	–	1,021	28,191
Employment (jobs)	953	4,000	1,558	–	248	6,759

After El-Raey et al. (1999)

loss of about 200,000 jobs by 2050, if no action were taken. Work is in progress to identify and assess vulnerable sectors in each district of the governorate.

Tables 6.3 and 6.4 show the results of the impact of SLR on the other two most important cities in the coastal zone of Egypt, Rosetta and Port Said, respectively (El-Raey et al. 1999). Again, results indicate serious impact and calls for advanced planning and adaptation measures.

The most important limitation on these results is the availability of recent land-use data and reliable topographic and socio-economic data. However, upgrading

Table 6.4 Economic evaluation of beach, urban, industry, agriculture, aqua-culture areas (km^2) municipal services and transportation network (km) losses of Port Said Governorate in case of Sea Level Rise of 50 cm

	Losses	Percentage (%)	value loss (million $)
Beach area (km^2)	21.26	1.60	2.126
Urban area (km^2)	0.46	7.80	48.0
Industry area (km^2)	0.05	12.50	5.0
Agriculture area (km^2)	0.00	0.00	0.00
Aqua-culture area (km^2)	0.024	0.12	2.40
Transport network (km)	23	11.73	4.60
Population (persons)	28,191	5.30	–
Employment (jobs)	6,759	5.30	–

the quality of topographic data using GPS (Geo-Positioning Satellites) and high resolution laser profilers, and building accurate geographic information systems (GIS) in an ARC/INFO environment, are now in progress (Mohamed et al. 2012).

5 Climate Change Impacts

Global warming is expected to affect Egypt in many ways. In particular, water resources, agricultural resources and coastal zones (see above) are expected to be adversely affected:

5.1 Impacts on Water Availability

A detailed quantitative assessment of the impacts of climate change on water resources in Egypt has yet to be produced. The demand for water in Egypt is dominated by three major user groups: agricultural irrigation, domestic use and industry. Even if no climate change takes place at all, the population is expected to double before the year 2050, if the present growth rate is maintained. A correspondingly rapid growth in agricultural and industrial output will be required to sustain this population. It is therefore likely that any effects of climate change on water supply and demand will be dwarfed by a much larger increase in demand due to population growth.

Due to the importance of predicting environmental impacts which could result from climate changes affecting the Nile basin several models have been advanced. Results of their predictions are summarized in Table 6.5 (after Strzepek et al. 1996).

It can be seen that these models are still incapable of predicting, with some certainty, what would happen if climate change occurs. However, the indictors call for serious action. In summary, the following impacts on water resources in the Nile river basin are expected:

Table 6.5 Model predictions of the impact of climate change on the Nile water budget

Model[a]	Temperature rise (K)	Water budget (bcm)	Percent
Base	0	86	100
GFDL	3.15	20	23
UKMO	4.73	76	88
GISS	3.45	112	130

[a]Current climate models

1. Increase of temperature increases losses by evaporation and demands for water for agricultural domestic and industrial applications increase.
2. Change of precipitation patterns will lead to a loss of water in coastal areas if proper storages are not available to collect runoff from upstream.
3. Increases in airborne dust levels, soil salinity and domestic use decreases water quality.
4. Sea level rise will increase occurrence of saline intrusion with contamination of groundwater resources in the coastal zone.

5.1.1 Water Resources

Both water supply and demand are expected to be affected by climate change. Impacts on the supply side are likely to arise from possible changes of precipitation patterns over the Ethiopian hills (which accounts for around 85 % of water flow into the River Nile), and equatorial lakes such as Lake Victoria (15 %). The effects of predicted climate change on both components are uncertain. The first is dependent on two factors, namely variation of the general cycle of the wind, and the El-Nino and ENSO phenomena. The second component is also uncertain due to increased frequencies of droughts and their intensities over the last two centuries. Rainfall on the upper White Nile catchment, the upper Blue Nile catchment, and the Middle Nile basin (which includes the confluence of the two major Nile tributaries), are all showing a decline in total rainfall and some change in rainfall intensity.

A combination of salt water intrusion due to Sea Level Rise (SLR) and increased soil salinity due to increased evaporation are expected to reduce the quality of shallow groundwater supplies in the coastal areas and this will impact both sown crops and other vegetation as well as those people who rely on groundwater for their business or for daily living.

5.2 Impact on Agricultural and Food Resources

Intensive, multiple cropping and high occupation rates are normal agricultural practices in Egypt. More than 6 million ha of crops are cultivated annually on 3 million ha of land, giving an intensity index of 2. (based number of crops per year etc.) Soil depletion is expected under such heavy land use unless sustainability measures are provided. Egypt is already a major cereal importer, and demand is expected to increase. As a result, the country is vulnerable to deficits in food production resulting from climate change. Expected higher prices for food imported from developed countries would aggravate the situation considerably.

Marginal agriculture and marginal farming are the most vulnerable, both to short term variations in local weather conditions and long term variation of climate. Adjusting to climate change will be made difficult by several factors: ownership of cultivated land is widespread but limited – 98 % of owners have a holding size of less than 5 ha each. Also, many types of farming are practiced near the edge of their appropriate climate zone. These marginal factors, along with under capitalization or low levels of financing, render farming particularly vulnerable to the effects of climate change (EEAA 1995). Livestock and fisheries are also vulnerable to the impacts of climate change, though changes in climatic conditions and sea level rise are expected to affect populations and various species differently.

In summary, the following climate changes impacts on agriculture are expected:

1. Increase of temperature and frequency of extreme events will reduce crop yield (some crops are more tolerant than others).
2. Change of average temperature will induce changes of the agricultural distribution of crops.
3. Increase of temperature will negatively affect marginal land and force farmers to abandon marginal land.
4. Shortage of water resources will also force farmers to abandon marginal land, and this will accelerate land degradation.
5. Socio-economic impacts associated with loss of jobs, such as increase of unemployment, loss of income, and political unrest.

An assessment of the impacts of climate change on some crops has been advanced (e.g. Eid et al. 1993). However, a detailed quantitative assessment of the impact of climate change on the agricultural sector, has not been carried out yet.

5.3 *Change of Precipitation, Wind Velocity and Heat Waves*

No assessment of the vulnerability of the coastal zones or inland areas to this impact is available for Egypt, nor is there any reliable model for prediction. However, the following impacts are to be expected to a greater or lesser degree:

1. Increased vulnerability of slum areas to wind and flood damage, and increased frequency of floods and fires in rural, as well as in some urban, areas. Settlements built in the path of old stream torrents will be particularly vulnerable.
2. Increased vulnerability of livestock due to shortage of water resources, increased salinity, and loss of grazing sites.
3. Changes in the frequency, timing and duration of heat waves will affect agricultural yields, and increase number and variety of insect pests.

5.4 Socio-economic Impact on Coastal Settlements

This will include the following:

1. Inundation and salt water intrusion will compel a significant proportion of the coastal zone population to abandon their land and homes.
2. Changes in the ecological system of lakes will reduce fish catches and drive away a large portion of fishermen and their dependents.
3. Loss of beaches will reduce the number of tourists in coastal areas, forcing tourism dependent individuals and communities to abandon their settlements and look for jobs elsewhere.
4. Increased saltwater intrusion will affect the management and access to archaeological sites; reduce tourism, and result in socio-economic impacts on the inhabitants of these areas.
5. Increased unemployment induces political and civil unrest.
6. Increased water-logging and salinity give rise to insect and pest problems which in turn causes health problems.
7. Increases in temperature lead to increased soil erosion and dust. Increased dust has direct adverse impacts on health, installations and equipment. Increased wind speed encourages sand dune movements and threatens coastal infrastructure.
8. Increased humidity and temperature decrease the human comfort zone, and reduce human productivity.

5.5 Regional Impacts of Accelerated Climate Change

Egypt is potentially one of the countries most at risk from the effects of climate change. It is located in an arid – to semi-arid zone. Its only source of water, the River Nile, provides more than 95 % of all water available to the country. The source of this water lies far to the south, from rainfall on Ethiopian hills (86 %) and equatorial lakes (14 %). Most of the population of Egypt (over 60 million people in total) is associated with the agricultural sector which constitutes 20 % of gross national product (GNP) and consumes about 80 % of the water budget.

The coastal zone of Egypt extends for more than 3,000 km and is the home of more than 40 % of the population. Most of these people live in and around a number of very important and highly populated industrial and commercial cities: Alexandria, Port Said, Damietta, Rosetta and Suez.

Alexandria city is one of the oldest cities on the Mediterranean coast, and is an important tourist, industrial and economic center. The city has a waterfront that extends for 60 km, from Abu-Qir Bay in the east to Sidi Krier in the west and includes a number of beaches and harbors. Alexandria's beaches are the main summer resort of the country, and its harbors are the most important import/export link between Egypt and Europe. About 40 % of all Egyptian industry is located within the governorate of Alexandria. As a result of its high population density and industrial pollution, environmental problems have affected a large sector of the community in the area.

A combination of salt water intrusion due to Sea Level Rise (SLR) and increased soil salinity due to increased evaporation are expected to reduce the quality of shallow groundwater supplies in the coastal areas. Rainfall measurements in coastal areas are contradictory and make it difficult to predict whether rainfall is increasing or decreasing.

In addition to its local impacts, climate change over Egypt has secondary regional impacts which also affect the international community. These include:

1. Increasing temperature increases soil erosion and wind speed, which in turn increases amount of Saharan dust carried across the Mediterranean to European countries causing health and economic problems.
2. Increased unemployment increases immigration pressure on European countries.
3. Decrease of water resources increases friction among countries sharing the same water resources (e.g. Nile and Euphrates), and leads to political unrest.
4. Increases in temperature and humidity increase rates of deterioration of Egyptian archaeological treasures which are considered among the most important in the world.

5.6 Government Response to the Climate Change Challenge

The coastal zone of Egypt is seriously vulnerable to the effects of sea level rise and changes in weather patterns from both the physical and the socio-economic points of view. Large areas of the governorates of Alexandria, Behaira, Kafr El-Shiekh, Port Said, Damietta and Suez, are particularly vulnerable to sea level rise. Other vulnerable areas include Lake Bardawil, coast of Obeyedh near Matruh and the coasts of the Bitter lakes. Many other areas on the Red Sea are also vulnerable. The coastal zones as a whole are also particularly vulnerable to changes in precipitation, excessive frequency of storm surges and changes in the heat pattern through the impacts of floods. The impacts of accelerated sea level rise (ASLR) through direct inundation, salt water intrusion, deterioration of ecological systems and associated socio-economic consequences, have been addressed. Impacts resulting from changes in the precipitation pattern, shortages of fresh water resources, loss of already scarce vegetation cover, increased desertification and associated socio-economic impacts, have yet to be studied in depth. The techniques and methodologies for vulnerability assessment of Egypt's coastal zones are reasonably well identified (e.g. IPCC methodology based on remote sensing and GIS). Although a quantitative pilot study has been carried out for one or more of the vulnerable areas (e.g. Alexandria governorate, Port Said.) current data on land use and elevation are needed before reaching a final overall assessment of the potential impacts of climate change on the coastal zones of the country. A program based on a strategic policy for coastal protection and adaptation must be advanced and implemented.

5.7 Adaptation to Climate Change in the Nile Delta Through Integrated Coastal Zone Management

UNDP in partnership with Ministry of Water Resources and Irrigation, Coastal Research Institute, The Egyptian Shore Protection Authority initiating a project aimed at strengthening Egypt's capacity to mitigate the impending problems of SLR, sea water incursion and other factors (see above) and adapt to the changing situation.

6 Egypt's National Environmental Action Plan (NEAP)

The NEAP addressed many environmental issues which included the three thematic areas: *climate change,* and *desertification*. The National Environmental Action Plan (NEAP) represents Egypt's agenda for environmental actions between years 2002 until 2017. It complements and integrates with sectoral plans for economic growth and social development and is the basis for the development of local environmental initiatives, actions, and activities. It is designed to be the framework that coordinates for future environmental activities in support of the sustainable development in Egypt. The NEAP includes programs and projects that address the environmental issues. Each program consists of three major components: information and monitoring, preventive and/or corrective measures, and supportive measures. Most of the information and monitoring activities are conducted by the EEAA. Most of the corrective and preventive measures are the responsibility of the central and local agencies in order to integrate environment protection into their plans.

6.1 Climate Change

Egypt is taking the issue of climate change seriously. The Nile Delta and coastal zones are prone to flooding due, in part, to rising sea levels. Agricultural productivity is another subject that climate change will potentially negatively affect as a result of increased average temperature. Human health is also at risk due to climate change. The increased temperatures might lead to the outspread of vector-borne diseases. Coral reefs are one of Egypt's natural resources that climate change adversely affects. Egypt seeks the help and support of the international community to mitigate the impact of climate change.

Egypt implemented two major projects in the field of climate change during the period 1995–1999. These projects were "Support for National Action Plan" and "Building Capacity for Egypt to Respond to UNFCCC". These projects ended in December 1999 by submitting Egypt's National Communication and establishing a

Climate Change Unit at EEAA as the institutional focal point for climate change. In addition, a support program to build the capacity to institutionalize Clean Development Mechanism (CDM) was completed successfully during November 2001 as a step towards implementing Egypt's strategy on CDM. The strategy includes, but not limited to, improving energy efficiency, promoting use of renewable energy, and expanding current activities for afforestation using treated wastewater to plant timber trees. The climate change targets are mainly improving energy efficiency, promoting use of renewable energy, (Box 6.1) and expanding current activities for afforestation using treated wastewater to plant wood trees.

Box 6.1: Renewable Energy Wind Power

Egypt had its wind potential assessed in 2003. With wind speeds of 7–10 m/s, almost the entire country is ideal for wind power, with the best areas in the Gulf of Suez coast. Then in 2008, the Egyptian government passed an ambitious plan to produce 20 % of its energy from renewables, with 12 % to come from wind. The Egyptian cabinet has approved inducements to wind power development, including exemption from customs duties and 20–25 year power purchase agreements with government guarantees. Now a 7,600 km^2 region has been earmarked by the New and Renewable Energy Authority (NREA) for wind development. NREA has obtained permits for land allocation and leases to wind farm developers. If successful, Egypt will get 12 % of its energy from wind power.

6.2 Desertification

Egypt, with land extending over one million square kilometers under arid and hyperarid climatic conditions, is endowed with varied agro-ecological zones (Fig. 6.1) with varied and specific attributes of resource base, climatic features, terrain and geomorphic characteristics, land use patterns and socio-economic implications. A meaningful national action plan for Egypt would be comprised of sub-components, each of which is geared to address the specific attributes of each agro-ecological zone distinguished in Egypt. The zones could be identified as follows:

1. North Coastal Belts: Including North West coastal areas and Northern areas of Sinai.
2. The Nile Valley: Encompassing the fertile alluvial land of Upper Egypt, the Delta and the reclaimed desert areas in the fringes of the old Nile valley.
3. The Oases and Southern Remote Desert Areas: Including Uwienate, Toshki and Darb El-Arbien Areas and Oases of the Western Desert.
4. The Desert Inland: Including the plateau and dry valleys of Sinai and elevated areas in the Southern Eastern Desert.

The general priorities in desertification in Egypt as presented in the NEAP tackled several issues, these are:

- Degradation of irrigated farmland as a result of using low quality water in irrigation.
- Degradation of rain-fed farmland (northern coastal belt and northern Sinai rainfall 100–250 mm), for insufficient water harvesting and water spreading processes.
- Degradation of rangeland (northern coastal belt) through overgrazing, degradation of plant cover.
- Encroachment of sand formations, especially from the Western desert, on the Nile Valley land (southern Egypt) and on the High Aswan Dam reservoir (in Egypt and Sudan).
- To formulate meaningful options that ensure that the introduction of irrigation into the area does not threaten the sustainable use of the marginal land or the livelihoods of the present local population.
- To conserve the ecosystem from invading pests and pollutants.
- To provide and enhance green areas for better and healthier microclimatic conditions.
- To formulate rational and innovative policies for waste management treatment and reuse of solids and effluents.
- To promote public awareness campaigns dealing with environmental issues using all available media means.
- To develop environmental institutional aspects with appropriate capacity building and training in issues specific to characteristics of the surrounding ecosystems.
- To combat damaging flash floods through appropriate water spreading and water conservation techniques; and to prevent and alleviate damages of flash floods to the infrastructures and available resources including adverse socio-economic impacts.
- To conserve, manage and utilize the highly valued and diversified natural flora and fauna resources.

The Desert Research Center works towards solving these problems (Box 6.2).

Box 6.2: Role of the Desert Research Center Arab Republic of Egypt Ministry of Agriculture and Land Reclamation

Desert Research Center is the Oldest Organization for Research and Development in the Desert and Newly Reclaimed Regions of Egypt.

Objectives

- Investigating desert potential for agricultural development.
- Carrying out studies on behalf of government institutions, societies and small landholders.

(continued)

Box 6.2 (continued)

- Preparing postgraduate research assistants and scholars for higher degree study in the field of scientific research.
- Conducting applied research and projects related to the development of desert and new reclaimed areas.
- Transfer of technologies to local farmers, Bedouins, investors, stakeholders, etc. through training and extension programs.

The work of the Ecology and Dry Lands Agriculture Division

Desertification control

Studies on sand dune fixation.

Establishment of wind screens for protection of newly settled area, towns, factories and desert roads.

Studies on the desert Ecosystem.

Mapping of vegetation and rangelands.

Evaluation of natural plant cover.

Studies on medicinal and aromatic plants of the Egyptian deserts.

Propagation of selected seedling adaptable to desert environments.

Co-operation with national and the international organizations in the field of agricultural research and biotechnology.

Run-off managements and its utilization for developing rainfed agriculture in the desert area. Conservation of plant collection. Seed banks

Production of cultivars and tolerance genotypes for biotic and a biotic stresses.

Increasing horticultural and field crop productivity by introducing new varieties.

Biological and ecological studies on plant diseases and pests

6.3 Egypt's National Action Plans in the Three Thematic Areas

The first commitment of the countries that ratified the UNFCCC, UNCCD and CBD is the preparation of National Action Plans (NAP) to mitigate and adapt climate change, combat desertification and to preserve biodiversity. According to the UN Conventions, the NAP should identify the factors contributing to climate change, desertification and biodiversity loss, and set up practical measures to reduce it.

The priorities considered in the NAPs are from the identified cross-cutting capacity in the prioritization phase of the NCSA project. The focus is only related to the prioritized cross-cutting issues: public participation; technology transfer and cooperation; financial mechanisms; legislation formulation and enforcement; and monitoring, evaluation, and reporting.

6.3.1 Climate Change

The climate change action plan was produced in 1999 and identified the following cross-cutting issues as priorities in its agenda to be considered in the policy of all involved entities: The improvement of national plans, programs and institutional capabilities; increasing scientific research capabilities, enhancement of technology transfer and cooperation; improvement of monitoring and evaluation systems; increase of public involvement and awareness of the issue; and the provision of training for people in the sector. In the climate change NAP, it addresses international cooperation in the field of climate change as an important issue that is essential for implementing most of the actions introduced in the climate change plan.

6.3.2 Desertification

In the desertification sector, the main priorities identified in the action plan that were cross-cutting with the other thematic areas are: development of national plans, programs and Institutional capabilities; improvement of legislation (both formulation and enforcement); enhancement of technology transfer and cooperation; improvement of monitoring and evaluation systems; increase of public involvement and awareness of the issue; the provision of training for people in the sector and the development of new funding strategies and financial mechanisms for combating desertification. In addition to increase of integration and cooperation with the biodiversity and climate change sectors.

Key issues:

- Enhance technical capabilities of some institutions to carry out comprehensive studies and follow-up of land degradation issues.
- The allocated funds for desertification control in eastern and western deserts including Sinai are relatively low.
- Division of labor between institutions needs to be more clearly specified. Improve coordination and institutional support.
- Need to incorporate combating desertification aspects into policies and planning
- Measurers taken for implementation of the convention are to be complemented and continued (according to the review of the previous activities that were completed in the NAP).

In the desertification NAP, it is stated that there should be measurements for the types and degrees of desertification and the rate of its extension in the four agro-ecological zones (Fig. 6.1) in Egypt should be monitored. In order to provide the decision makers with relevant analyses of the desertification processes. It is also stressed that it is important for Egypt to obtain technical assistance from concerned regional and international institutions as well as from other developed countries and donors and to adopt innovative technologies for halting the desertification processes. It is further stated that additional legislation and regulations at the national, governorates and local levels will be needed as well as enforcement of existing and newly issued legislations and regulations are also needed to support efforts and activities of combating desertification in the different agro-ecological zones.

There should be participation of local communities, targeted groups, stakeholders, and NGOs in planning, implementation, evaluation and monitoring. Up-grading the capacity of the local community, NGOs, institutions and all partners in the various aspects of desertification control is an essential prerequisite for NAP success. The promotion of public awareness campaigns dealing with environmental issues, particularly combating desertification, should be done using all available media. Awareness raising in the field of desertification control in general and rangeland management and sand dunes fixation in particular should be the focus.

6.3.3 Biodiversity

The issues tackled in the biodiversity action plan related to the requirements of the CBD are: Development of national plans, programs and institutional capabilities; improvement of legislation (formulation and enforcement); enhancement and increasing scientific research capabilities; enhancement of technology transfer and cooperation; improvement of monitoring and evaluation systems; increase of public participation and the incorporation of biodiversity into public education. Also, the provision of training for people in the sector and the development of new funding strategies and financial mechanisms are within these Priorities.

In the NEAP, one of the goals of biodiversity conservations is developing Egyptian scientific and technological capabilities in fields of conservation. In the biodiversity NAP, it is stated that the Nature Conservation Authority should use internationally recognized best practices to achieve the standards of excellence expected by the Convention on biodiversity.

Allocating adequate permanent financing resources required for combating desertification. Financial assistance to Egypt should be obtained from concerned regional and international institutions as well as from other developed countries and donors, additional funds through GEF, the Global Mechanism, World Bank, the International Fund for Agricultural Development, etc. An important point that was declared in the national consultation workshop is that Egypt is in the process of establishing a national fund for implementation of UNCCD obligations as part of the NAP projects.

Additional legislation and regulations at the national, governorates and local levels will be needed. Enforcement of existing and newly issued legislations and regulations are also needed to support efforts and activities of combating desertification in the different Agro-ecological zones.

The NAP states that there should be measurements for the types and degrees of desertification and its extension in the four agro-ecological zones in Egypt should be monitored. In order to provide the decision makers with relevant analyses of the desertification processes. A system to monitor the impact of desertification should be set up to quantify the extent, intensity of land degradation on special scale and some indications on temporal scale. Thematic maps and creation of relevant indicators should be generated to inform stakeholders and decision makers regularly with the scope of the desertification phenomena and provide them with an objective basis for making related plans.

7 Recommended Lines of Action to Implement the National Conservation Strategy and Meet the Objectives of the NAPs

Usually in Egypt, the same as in most developing countries, there is a gap between most written action plans and their implementation on the ground. In order to ensure that the National Conservation Strategy and Action Plan is implemented; several practical, simple, and clear measures need to proposed and agreed upon.

7.1 Cross Cutting Issues Relevant to Desertification and the Other Two Rio Conventions

Several actions were recommended in the in-depth phase of the NCSA project to address the main prioritized constraints specifically and all the gaps that were noted in the stocktaking and gap identification phase generally. These actions should be applied to achieve the goals of the three Rio conventions (Biodiversity, Desertification, Climate change). These actions are in the area of ***Public Participation; Technology Transfer and Cooperation; Financial Mechanisms; Legislation Formulation and Enforcement; and Monitoring, Evaluation, and Reporting***.

7.2 Development Framework

The requirements of the three Rio Conventions, as well as the principles emerging from the cross-cutting/synergy analysis of the NCSA process. For accomplishment of the capacity development objectives, the responsible entities should be governed by the following strategic principles:

7.2.1 National Ownership and Leadership

The efforts should be nationally owned, led and driven, including strategic planning, self-monitoring, and self-evaluation. A high degree of national political commitment is essential, but in the same time there should be decentralization in responsibilities.

7.2.2 Stakeholders' Participation and Partnership

Multiple stakeholders should be involved in national decision making and have shared responsibility in implementation to maximize impact and create synergies.

7.2.3 Holistic and Integrated Approach

Capacity-building efforts should be realistic, recognize and build on existing strengths, knowledge and experience. Capacity development must be integrated with ongoing initiatives to enhance capacities for broader environmental managements and for sustainable development in general without duplication of efforts or resources. Parallel to this, the outcomes of the action plan should be taken in consideration in national planning and decision-making.

7.2.4 Flexibility

Capacity-building efforts should be supported by a variety of tools and methodologies. These could range from the more traditional methods to capacity building (such as workshops, training, awareness raising, etc.) to those that offer greater scope both methodologically and institutionally, such as networking, horizontal exchanges and cooperation. Capacity building is a dynamic process therefore adequate monitoring and evaluation techniques are essential for adaptive management and improvement.

7.2.5 Improving Inter-agency Coordination

A number of different entities are concerned with the thematic areas of the three Rio Conventions. Currently coordination between these different agencies and entities is random, particularly with regards to monitoring, evaluation and reporting. This leads to significant hindrances to effective monitoring evaluation and reporting, with adverse effects on the inclusion of global environmental issues in national policies and plans.

8 Summary and Conclusions

The government has addressed many environmental issues which included the three thematic areas: *climate change, desertification and biodiversity*. The National Environmental Action Plan (NEAP) represents Egypt's agenda for environmental actions between years 2002 till 2017. It complements and integrates with sectoral plans for economic growth and social development and is the basis for the development of local environmental initiatives, actions, and activities. It is designed to be the framework that coordinates for future environmental activities in support of the sustainable development in Egypt. Agricultural productivity is another aspect that climate change will potentially negatively affect as a result of increased average temperature. Human health is also at risk due to climate change.

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Part III
Deserts and Desertification in Other African Countries

There are four chapters in this part. The focus shifts first to East Africa and southern Africa with examples from Kenya and Lesotho. Because of the differences in climate, population density, stage of development and predominant land use there are differences in the approach to desertification control.

Lesotho is a mountainous country with soils that are erosion-prone. The land use practices are a cause of accelerated land degradation. Combating desertification and accelerated land degradation involves a focus on soil erosion control. Kenya has more varied suite of landscapes from mountains to vast plains. Livestock husbandry plays an important role in the land use pattern and brings with it a series of problems related to rangeland degradation, but Kenya also has large number of subsistence farmers and has made many efforts to control soil loss, and excessive fuel wood collection is part of the strategy.

Desertification and accelerated land degradation are problems throughout Africa as these four examples show. Chapter 9 from Chad deals with the problems of a small landlocked country surrounded by desert, whilst the efforts in Niger in the aftermath of the Medium Term Action Plan (MTAP) are outlined in Chap. 10.

Chapter 7
Combating Desertification in Kenya

P.M. Nguru and D.K. Rono

Synopsis The UNCCD implementation process for Kenya is explained and a number of measures taken in several important projects are elaborated. There were three broad overlapping phases: *Phase 1:* Creating an Enabling Environment. *Phase II:* Formulation and Elaboration of the NAP. *Phase III:* Implementation, Follow-ups and Evaluation.

Key Points

- Kenya is faced with land degradation and desertification and it is committed to combating desertification as reflected in its National Action Program (NAP) as per the provisions of the UN Convention to Combat Desertification (UNCCD). This Framework involves the inclusion of stakeholders in desertification combating initiatives. The NAP implementation process also recognizes four levels of operation, namely sub-regional, national, provincial/district and community levels and it is worth noting that some achievements have been realized in its implementation at the community level. These include development of various policies; strategies and development initiatives aimed at integration of the development of the Arid and SemiArid Lands (ASALs) into the national development frameworks. However, the country faces myriad challenges in its efforts to combat desertification, which include the growing imbalance between human population, resource utilization, development and environment.
- Drylands are rapidly changing to the detriment of the environment. Increased number of livestock owned by migrants into ASALs has reduced the carrying capacity of these lands. The conversion of key livestock production areas to crop production as well as the establishment of 59 National Parks and Game Reserves

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in arid and semi-arid lands has also substantially reduced access to alternate wet and dry season grazing areas for the pastoralists.
- Strategies to combat desertification are faced with many challenges, which include lack of general education and awareness with perceptions varying widely among stakeholders, climatic constraints, limited expertise in various fields, limited financial resources and mechanisms, poverty which is acute in most affected areas and inappropriate and/or inadequate policies and coordination mechanisms. Effective prevention of desertification requires both local management and macro policy approaches that promote sustainability of ecosystem services. Measures to arrest and reverse desertification are tailored to the local circumstance. The most effective are those that work with local communities.

Keywords Resources utilization • Land degradation • Desertification • Success story • Local involvement • Wildlife • Stakeholders • Pests and diseases of livestock • Ecosystem services • Red meat • Rural livelihoods

1 Introduction

1.1 Profile of Kenya

Kenya lies on the eastern coast of the African continent, between latitudes 5°40′ north and 4°4′ south and between longitudes 33°50′ and 41°45′ east. The Equator bisects the country into two almost equal parts. Total land area is approximately 590,000 km^2. Most of the country lies within the eastern end of the Sudano-Sahelian belt, a region often affected by drought and desertification in Africa. Kenya has diverse landforms ranging from the coastal plains through the dry Nyika plateau to the savanna grasslands and the highlands on either side of the Rift Valley. Mount Kenya, the Mau Ranges, Mount Elgon and the Aberdare Range dominate the highlands that are traversed by the Great Rift Valley. The vast expanse of northwestern, northern, eastern and southern parts of Kenya varies from flat semi-desert in the east to the more rugged country west of Lake Turkana. The coastal region is narrower in the south but widens out in the north with an altitude range of 0–400 m above sea level. Mountains and hills, including the Taita Hills and Chyulu range mark the western limits of the coastal region. The Nyika Plateau and the Coastal Region are the areas mainly affected and threatened by desertification.

1.2 Climate

Physiography to a large extent influences rainfall potential and subsequently, water resources. For instance, the topographic heights determine the windward and leeward side with the former having more rainfall. For example, the flanks of the western and eastern sides of the Rift Valley have higher rainfall than the Rift Valley floor. "Relief" rainfall occurs on the windward side of high areas while 'convectional' rainfall is experienced in predominantly flat areas, especially near large water bodies like Lake Victoria. Further, the seasonal northward and southward movement of the inter-tropical convergence zone (ITCZ) has enormous influence on the climatic condition of the country. ITCZ produces two rainy seasons – March–May (long rains) and October-November (short rains). The coastal belt is relatively wet with more rainfall in the south. The Nyika plateau is generally arid and semi-arid. The highlands receive moderate to very heavy rainfall. The mean annual rainfall ranges between 250 and 1,000 mm in dry lands. Although the rains are experienced in two distinct seasons, they are erratic in both temporal and spatial terms. The temperatures are relatively high and account for annual potential evaporation, which is often above 2,500 mm. The rainfall and the potential evaporation have been the cause of frequent crop failure in the drylands.

Climatic variation is the main cause of droughts in Kenya. According to the Intergovernmental Panel on Climate Change Third Assessment Report, 2001, climate will be associated with rise of mean temperatures by the year 2025. The change is likely to increase the intensity and frequency of drought. Droughts that have occurred in Kenya have caused heavy losses in terms of crop failure, deaths of livestock and human beings and heavy investments for purchase of relief food. It is anticipated that the projected climate change by the year 2025 will exacerbate the losses already experienced due to drought.

1.3 Arid and Semi Arid Lands (ASALs)

Over 88 % of Kenya's total land is classified as Arid and Semi Arid Lands (ASALs) that fall under three Agro-Ecological Zones (Fig. 7.1). This land supports 26–30 % of the total population: 50 % of the livestock sector as well as the wide variety of the wildlife that forms the basis of Kenya's tourism industry.

Sixty seven percent (67 %) of the total red meat produced in the country comes from the ASALs and is produced from a livestock population estimated at 8.9 million beef cattle, 5.9 million sheep and 7.7 million goats and 0.85 million camels.

An assessment of Kenya rangelands indicates that, over the country as a whole, perennial grass cover has decreased whereas annual grass, woody cover and the amount of bare ground have increased. The human population in ASALs is growing at a faster rate than in the high potential areas. The growth is heavily influenced by natural increase and migration of people from the high potential areas mainly in search of land and employment opportunities. The major challenge now is how to sustain ASAL productivity while simultaneously providing sustenance or livelihood for more people. In Kenya, rural dryland populations are dependent on the environment/natural resource base for food, water and fuel hence degradation of these assets makes it increasingly difficult for populations to obtain their basic needs there by accelerating the incidence of poverty.

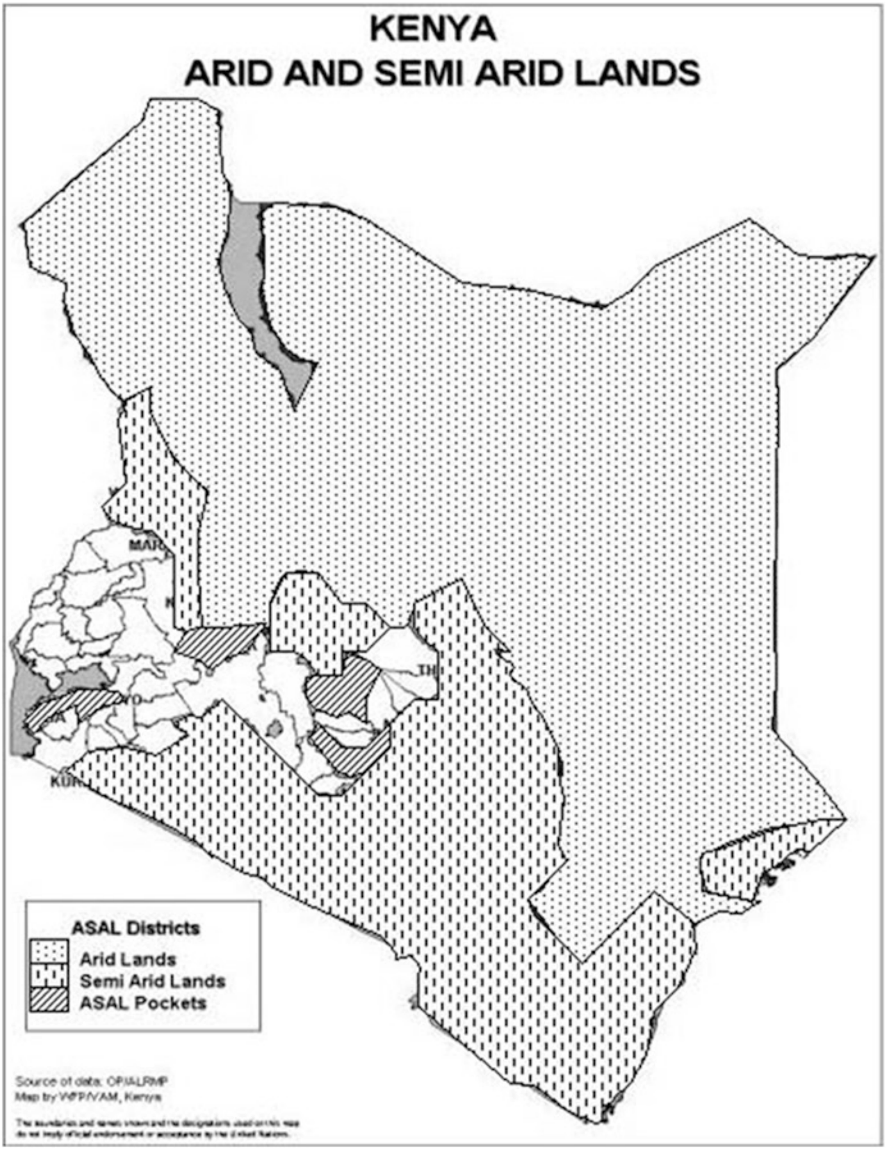

Fig. 7.1 Kenya map showing Arid and Semi-Arid Lands (ASALS)

Drylands are rapidly changing to the detriment of the environment. Increased number of livestock owned by migrants into ASALs has reduced the carrying capacity of these lands. The conversion of key livestock production areas to crop production as well as the establishment of 59 National Parks and Game Reserves in ASALs (Fig. 7.2) has also substantially reduced access to alternate wet and dry season grazing areas for the pastoralists.

Fig. 7.2 Extensive rangelands are used by traditional pastoralists. Much of the better land has been put into national parks. Large areas have become degraded outside of the reserves

2 Desertification in Kenya

Desertification is a major environmental and socio-economic problem, affecting about 80 % of Kenya. A total of 7–10 million inhabitants residing in this area suffer from widespread acute poverty and other adverse effects of drought. Consequently, Kenya has no option but to institute necessary anti-desertification measure.

Previous Government efforts to combat desertification and mitigate the effects of drought have fallen short of desired impacts because of different reasons. These include sectoral approach in the implementation of measures with weak institutional linkages such as coordination; wastage of resources due to duplication of efforts, budgetary constraints – both in terms of the amount of funds allocated and the viability of such funds; and, lack of project ownership by the beneficiaries. It is in realization of the above that more efforts need to be put in place in order achieve sustainable development in the drylands of Kenya through strategies for poverty alleviation, food security and environmental conservation.

2.1 Combating Desertification in Kenya

Desertification is a complex physiographic process caused and accelerated either by natural or man-induced factors. The natural causes of desertification are mainly related to climatic peculiarities and condition, such as extreme aridity, uneven distribution of precipitation throughout a year and its variability from one year to another, frequent recurrent of drought, low air humidity and or high values of temperature. Man-induced causes are related to poor planning and management in exploitation of natural resources to meet the daily demands and increase of population. In broader term, these would include overgrazing, deforestation, poor land management and policies among others. All these lead to the reduction of quantity and deterioration of the quality of renewable natural resources such vegetation, soil, water and changes in fauna.

2.2 United Nation Convention to Combat Desertification

The origins of the United Nation Convention to Combat Desertification and mitigate the effects of Drought (CCD) can be traced to the devastating drought in the Sudano-Sahelian region 1968–1974 which led to the birth of UNSO in the UN. The real turning point came during the Earth Summit in Rio de Janeiro when the United Nations Conference on Environment and Development (UNCED) recommended to the UN General Assembly for the negotiation for the CCD.

Kenya participated fully in the CCD's negotiations that began in early 1993. They were finalized and the Convention opened for signing in June 1994. It entered into force on 26th December 1996. As part of her commitment to address the problems of desertification under the CCD, the Kenya government signed the convention in October 1994 and ratified it in June 1997. Kenya participated in the first conference of the parties (COP) held in Rome October/November 1997. Over 129 countries had ratified the convention by the beginning of 1998 and many more followed.

The CCD defines Desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. The convention calls for the implementation of activities aimed at prevention and/or reduction of land degradation, rehabilitation of partly degraded land and reclamation of lands already desertified. The scourge affects over 5.2 billion hectares and about 1 billion people worldwide in over 100 countries. It is closely interrelated to other UN environmental conventions such as the Convention on Biological Diversity (CBD), the Framework Convention on Climate Change (FCCC). The Convention to Combat Desertification (CCD) and the Forestry Principles are the direct result of the 1992 United Nations Conference on Environment and Development, the 'Rio Earth Summit.' The inter-relation of the four conventions should also extend to other environmental treaties such as CITES, Ramsar, the Montreal Protocol and The Law of the Sea.

These conventions all address issues of importance to people living in the drylands. However, the implementation of environmental issues is sector-oriented. The question, therefore, is how to ensure that these instruments can be implemented in an integrated manner and benefit people living in Kenya's drylands. In short, an integration that reduces the burden of the local person but still enables the implementing bodies to address their sector concerns. In Kenya, it is possible within sector planning. For example, the Convention on Biological Diversity can be addressed within the Wildlife Conservation and Management Strategy.

Globally, there have been many different attempts to combat desertification. The first major international effort was the 1977 Plan of Action to Combat Desertification (PACD) formulated in Nairobi. PACD and other interventions have had little impact on desertification, because of various reasons. Past efforts, which were mostly top-down processes, have, for instance, lacked the ability to institute the measures and mobilize sufficient resources required for sustainable development. The search for an alternative strategy culminated in the CCD that came as a recommendation of UNCED in June 1992. The CCD, although a global agreement, was an African initiative that pushed for adoption of a convention whose activities and programs will be people centered and demand driven through people's participation in consultative processes and actual implementation as a central strategy to implement the CCD. This would include poverty alleviation activities that address the root causes of desertification.

Since the Kenya Government signed the convention, it has been making various efforts with a view to implementing the provisions of the convention in collaboration with NGOs and other stakeholders through the National Action Program as a tool for implementing the provision of the CCD, Country report (2002). This will be possible through concerted efforts under efficient coordination, cooperation and in a spirit of partnership with focused but differentiated roles for the different stakeholders. Thus, although there are already a number of efforts addressing desertification, there is need for joint efforts from all stakeholders (the government, the donor community, the private sector, NGOs and CBOs etc.). The main objectives would be to expand financial sources, reduce duplication of efforts and development conflicts, and increases resource use efficiency and effectiveness. For example, the CCD recognizes that financing the anti-desertification activities should not be the responsibility of the government alone.

2.3 UNCCD Implementation Process in Kenya

The Government in collaboration with NGOs and other stakeholders considers the implementation process as constituting the following three broad overlapping phases:

Phase 1: Creating an Enabling Environment. The aim of this phase would be to institute the mechanisms and processes necessary to ensure that all the stakeholders are involved in the design of the action program.

Phase II: Formulation and Elaboration of the NAP. During this phase the national, local area and community action programs would be designed. Community Action Plans (CAPs) would be initiated and implemented to a large extent.

Phase III: Implementation, Follow-ups and Evaluation. This phase marks the beginning of full implementation of the national and local area action programs, which like the CAPs should be fairly flexible and iterative to allow for as many revisions as lessons and experiences are gained.

However, it should be recognized that the implementation of the CCD is going to be complex and a long-term process. This is because combating desertification is about sustainable development in the drylands, and therefore is a complex interaction between economic, socio-cultural, political and environmental issues, which vary from one area to another.

It should also be appreciated that desertification and land degradation is caused by various natural and human actions in combination with gradual and mostly insidious effects and sometimes with immeasurable weights such as climatic effects, poverty, inappropriate land, use over cultivation, overgrazing due to overstocking, and de-vegetation for construction timber and energy.

Strategies to combat desertification are faced with many challenges, which include lack of general education and awareness with perceptions varying widely among stakeholders, climatic constraints, limited expertise in various fields, limited financial resources and mechanisms, poverty which is acute in most affected areas and inappropriate and/or inadequate policies and coordination mechanisms.

Effective prevention of desertification requires both local management and macro policy approaches that promote sustainability of ecosystem services. It is advisable to focus on prevention, because attempts to rehabilitate desertified areas are costly and tend to deliver limited results. The creation of a "culture of prevention" can go a long way toward protecting drylands from the onset of desertification or its continuation. The culture of prevention requires a change in governments' and peoples' attitudes through improved incentives. Young people can play a key role in this process. Evidence from a growing body of case studies demonstrates that dryland populations, building on long-term experience and active innovation, can stay ahead of desertification by improving agricultural practices and enhancing pastoral mobility in a sustainable way. For example, in many areas of the Sahel region, land users are achieving higher productivity by capitalizing on improved organization of labor, more extensive soil and water conservation, increased use of mineral fertilizer and manure, and new market opportunities.

Major policy interventions and management approaches are needed to prevent and reverse desertification. Assessment of future scenarios shows that major interventions and shifts in ecosystem management will be needed to overcome challenges related to desertification. As recognized by the UNCCD, such interventions are to be implemented locally, with the active engagement of stakeholders and local communities, with improved information generation and access.

Integrated land and water management are key methods of desertification prevention. All measures that protect soils from erosion, salinization, and other forms of soil degradation effectively prevent desertification. Sustainable land use can address human activities such as overgrazing, overexploitation of plants, trampling of soils, and unsustainable irrigation practices that exacerbate dryland vulnerability.

Fig. 7.3 Photo sequence from (**a**) 2004 to (**d**) 2007 of a typical site where controlled access has resulted in vegetation recovery

Management strategies include measures to spread the pressures of human activities, such as transhumance (rotational use) of rangelands and well sites, stocking rates matched to the carrying capacity of ecosystems, and diverse species composition. Improved water management practices can enhance water-related services. These may include use of traditional water-harvesting techniques, water storage, and diverse soil and water conservation measures. Maintaining management practices for water capture during intensive rainfall episodes also helps prevent surface runoff that carries away the thin, fertile, moisture-holding topsoil. Improving groundwater recharge through soil-water conservation, upstream revegetation, and floodwater spreading can provide reserves of water for use during drought periods.

Protection of vegetative cover can be a major instrument for prevention of desertification. Maintaining vegetative cover to protect soil from wind and water erosion is a key preventive measure against desertification. Properly maintained vegetative cover also prevents loss of ecosystem services during drought episodes. Reduced rainfall may be induced if vegetation cover is lost due to over cultivation, overgrazing, over harvesting of medicinal plants, woodcutting, or mining activities. This is usually coupled with the effect of reduced surface evapotranspiration and shade or increased albedo (Fig. 7.3).

In the dry humid and semiarid zones of Kenya, conditions equally favor pastoral and cropping land use. Rather than competitively excluding each other, a tighter cultural and economic integration between the two livelihoods can prevent desertification. Mixed farming practices in these zones, whereby a single farm household combines livestock rearing and cropping, allows a more efficient recycling of nutrients within the agricultural system. Such interactions can lower livestock pressure on rangelands through fodder cultivation and the provision of stubble to supplement livestock feed during forage scarcity (and immediately after, to allow plant regeneration) due to within- and between-years climatic variability. At the same time, farmland benefits from manure provided by livestock kept on fields at night during the dry season. Many Kenyan farming systems are based on this kind of integration of pastures and farmland.

Use of locally suitable technology is a key way for inhabitants of drylands at risk of desertification to work with ecosystem processes rather than against them. Applying a combination of traditional technology with selective transfer of locally acceptable technology is a major way to prevent desertification. Conversely, there are numerous examples of practices—such as unsustainable irrigation techniques and technologies and rangeland management, as well as growing crops unsuited to the agroclimatic zone—that tend to accelerate, if not initiate, desertification processes. Thus technology transfer requires in-depth evaluation of impacts and active participation of recipient communities (see also Chap. 21). Local communities can prevent desertification and provide effective dryland resource management but are often limited by their capacity to act. Drawing on cultural history and local knowledge and experience, and reinforced by science, dryland communities are in the best position to devise practices to prevent desertification. However, there are many limitations imposed on the interventions available to communities, such as lack of institutional capacity, access to markets, and financial capital for implementation. Enabling policies that involve local participation and community institutions, improve access to transport and market infrastructures, inform local land managers, and allow land users to innovate are essential to the success of these practices. For example, a key traditional adaptation was transhumance for pastoral communities, which in many dryland locations is no longer possible. Loss of such livelihood options or related local knowledge limits the community's capacity to respond to ecological changes and heightens the risk of desertification.

Desertification can be avoided by turning to alternative livelihoods that do not depend on traditional land uses, are less demanding on local land and natural resource use, yet provide sustainable income. Such livelihoods include dryland aquaculture for production of fish, crustaceans and industrial compounds produced by microalgae, greenhouse agriculture, and tourism-related activities. They generate relatively high income per land and water unit in some places of Kenya. Dryland aquaculture under plastic cover, for example, minimizes evaporative losses, and provides the opportunity to use saline or brackish water productively. Alternative livelihoods often even provide their practitioners a competitive edge over those outside the drylands since they harness dryland features such as solar radiation, winter relative warmth, brackish geothermal water, and sparsely populated pristine areas that are often more abundant than in non-drylands. Implementation of such practices in drylands requires institution building, access to markets, technology transfer, capital investment, and reorientation of farmers and pastoralists.

Desertification can also be avoided by creating economic opportunities in drylands urban centers and areas outside drylands. Changes in overall economic and institutional settings that create new opportunities for people to earn a living could help relieve current pressures underlying the desertification processes. Urban growth, when undertaken with adequate planning and provision of services, infrastructure, and facilities, can be a major factor in relieving pressures that cause desertification in drylands. This view is relevant when considering the projected growth of the urban fraction in drylands in Kenya, which will increase to around 52 % by 2010 and to 60 % by 2030.

3 Reversal of Land Degradation

The goal of rehabilitation and restoration approaches is to restore ecosystem services that have been lost due to desertification. This is achieved through a positive change in the interaction between people and ecosystem. Restoration is an alteration of a degraded site to reestablish a defined native ecosystem state and all its functions and services. Rehabilitation seeks to repair damaged or blocked parts or sectors of ecosystem functions, with the primary goal of regaining ecosystem productivity. Like the benefits of increased education or improved governance, the protection, restoration, and enhancement of ecosystem services tend to have multiple benefits.

Effective restoration and rehabilitation of desertified drylands require a combination of policies and technologies and the close involvement of local communities. Examples of measures to restore and rehabilitate include establishment of seed banks, restocking of soil organic matter and organisms that promote higher plant establishment and growth, and reintroduction of selected species. Other rehabilitation practices include investing in land through practices such as terracing and other counter-erosion measures, control of invasive species, chemical and organic nutrient replenishment, and reforestation. Policies that create incentives for rehabilitation include capacity building, capital investment, and supportive institutions. Community involvement in conceptualization, design, and implementation is essential for rehabilitation approaches. For example, many of the policies for combating desertification tried in the Sahel during the 1970s and 1980s failed because they did not involve local land managers. An example of a success story is the work reported by Mugova and Mavunga (2000).

For desertified areas, rehabilitation strategies have a mix of positive and negative impacts on ecosystems, human well-being, and poverty reduction. The success of rehabilitation practices depends on the availability of human resources, capital for operation and maintenance, infrastructure development, the degree of dependence on external sources of technology, and cultural perceptions. Adequate access to these resources, combined with due consideration of the needs of local communities, can lead to successful rehabilitation of some ecosystem services and hence reduce poverty. Some success stories have been observed; for example, farmers in the Machakos (Kenya) restored degraded lands. This was achieved through access to markets, off-farm income, and technologies that increased land and labor productivity faster than population growth.

In Kenya the use of payments for ecosystem services, mostly around the country's reserves and parks—where people live close to wildlife—is providing a stable, reliable and predicable source of income to pastoralists with the double advantage of reducing poverty and protecting wildlife. In many sites where payments for ecosystem services have be piloted successfully, local-level institutions have played a significant role in enabling communities to self-govern and are supported by flexible land-use and governance systems that respect the communal land ownership patterns that have traditionally existed in these areas. Payments to livestock herders for the ecosystem services generated through their land uses are currently being made in lands adjacent to Kenya's famous Masai Mara National Reserve, in the southwest of the country, and in the Kitengela wildlife dispersal area to the south of Nairobi National Park.

In both areas, Maasai people have formed 'eco-conservancies' to protect their grazing areas for livestock and wildlife alike. In cases where these conditions are not met, efforts to rehabilitate fail. Box 7.1 sets out specific actions taken by both governments and local people. With all the projects listed, lack of funds is the major constraint.

Box 7.1: Actions Taken at National and Local Level That Lead to Situation Betterment

Projects at National level

1. Establishment of an environmental information centre.
   A preliminary proposal was prepared, funded by UNSO and UNEP. More recently support has come from the East African Biodiversity Project.
2. Monitoring desertification in Kenya dry lands.
3. Establishment of radio programs. It is intended to expand this to television.
4. Integrated development of range farming and wildlife management in the pastoralist divisions. Using livestock as a tool to help rehabilitate degraded land (Northern Rangelands (Samburu))

Activities at local Community level

1. Reinforcement of rangeland areas with legumes
2. Grasslands should be harvested when they are most nutritive and stored as high quality hay for dry season feeding
3. Grazing reserves should be established

(continued)

Box 7.1 (continued)
4. Salt licks and improved pastures should be used in grazing areas to spread utilization
5. Improve efforts to eradicate tsetse flies and other pests causing livestock disease
6. Use of fire, selectively burning areas at the appropriate time.

4 Conclusions

There exist policies, institutions and legal structures on desertification combating that should be strengthened with a view to mainstreaming all levels of decision making. This will involve strengthening the national procedures to negotiate and implement the UNCCD. Further, there is need to build more capacity to improve on coordination, harmonization, implementation, monitoring and evaluation of programs and projects on combating desertification. Appropriate mechanism under which the private sector, NGOs and CBOs may contribute to support NAP activities will also be enhanced. Needs to strengthen programs initiated in order to reach the grassroots, where the problems of desertification and poverty are interrelated. Coordination and cooperation are needed to ensure the efficient utilization of available resources.

Development of appropriate institutional structures for implementation of the convention to combat desertification should receive priority for attention. This must be viewed within the overall framework for operating national policies.

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Chapter 8
Lesotho: Desertification Control Program

S. Moshoeshoe and M. Sekantsi

Synopsis This is an overview of the situation in Lesotho with a brief summary of what the problems are and how this small mountain kingdom is dealing with them.

Key Points

- Lesotho has been faced with a problem of desertification since early 1900s. This is as a result of overgrazing (which causes inadequate vegetative cover in the rangelands), drought, torrential rains which come during one season, communal land use (Tragedy of the commons), deforestation and improper land use practices. As a result of these and the topographic nature of the country and highly erosive soils, there is formation of gullies, which drops the water table and makes it impossible for vegetation growth. These further threaten the ecological system and hence cause desertification.
- Degradation of rangelands presents the biggest challenge to Lesotho and a serious loss to biodiversity. Lesotho is experiencing a high loss of soil largely as a result of poor range management practices. Rangelands are communally used under control of the chieftainship. As mitigation, the government is encouraging the establishment of grazing associations in order to turn rangelands into a common property resource. Each grazing association is given an area (range management area) that it controls. It is believed that because of private gain,

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livestock owners will tend to manage and use their range management area sustainably. There are big challenges facing this new policy however largely rooted in group dynamics and political will.

Keywords Mechanical measures • Biological measures • Degradation • Rehabilitation and small scale irrigation • Overgrazing • Gullying • Water table • Drakensberg • Alpine • South Africa • Orange River • Wind erosion • Grazing associations • Fuel wood • Afforestation • Tragedy of the commons

1 Geographical Information

Lesotho is a mountainous country (Fig. 8.1) with a total surface area of 30,334 km^2 and is completely landlocked by the Republic of South Africa (Fig. 8.2). The country is situated at the highest part of the Drakensberg escarpment of the eastern rim of the Southern African plateau, between 1,500 and 3,482 m above sea level; and between 28–31° southern latitude and 27–30° eastern longitude (Fig. 8.2). It is administratively divided into ten districts, which fall within the general classification of four physiographic regions based on the elevation and climate. The lowlands range from 1,500 to 1,800 m in elevation and make up about 20 % of the land area, a long a narrow belt 20–50 km wide along the western border. Over 80 % of the productive arable lands – and coincidentally the highest population densities are in this region.

Fig. 8.1 Mountains occupy a large part of Lesotho

Fig. 8.2 Map of Lesotho, a land locked mountainous country in southern Africa

The foothills have elevations ranging from 1,800 to 2,000 m and form a narrow strip running northeast to southwest, adjacent to the lower mountain range. This region covers 10 % of the country and also supports high population densities. The Senqu/Orange River Valley, between 1,500 and 1,800 m above sea level, is a major grassland area, marked by shallow soils and this make up about 11 % of the land area. The population in this region depends largely on livestock and mixed farming. The mountains range from 2,000 to 3,400 m and are primarily used for summer grazing. They host some unique African alpine and sub-alpine habitats of the Drakensberg range and they make up about 59 % of the land area.

Lesotho is generally classified as temperate, with the highlands areas experiencing severe winters with ground frost up to 200 days a year. Such climatic conditions undoubtedly limit the scope of crop diversity. The average annual rainfall is 780 mm per annum, of which 85 % falls between October and April. The precipitation is uneven, ranging from 450 mm in the southern and western lowlands to 1,600 mm in the northern lowlands and eastern highlands. The occurrence of summer rains is an important factor in subsistence crop production in Lesotho. The tropical and climatic variations impose severe constraints on agriculture; only 13 % of the land is suitable for arable cropping and in recent years, this has dropped to about 9 % because of extensive land degradation, gully erosion, residential and industrial encroachment.

Furthermore, the country exhibits marked seasonality, with even the lowlands experiencing winter frosts. Temperature in the lowlands fluctuates around 30 to −5 °C. Topography has played an important role in the formation of the soils of Lesotho because of variations in slope and altitude. On steep slopes in the mountains, soils development is impaired because of the greater influence of erosion and low temperature, which led to the formation of immature skeletal soils. In the foothills, where volcanic materials meet the sedimentary formations, colluvial activities have caused a great deal of variation in the geological materials. In the lowlands, most of the soils contain dissolved material and suspended fine clay through the lateral flow of water from soils on the surrounding slopes to depressions and bottom lands subsequently forming hydromorphic soils.

2 Desertification in Lesotho

Soil erosion has been a problem in Lesotho since the early 1900s. A lot of rehabilitation work has been done in the past but the rate of soil erosion is still high and land degradation caused by drought, torrential rains and overgrazing which lead to inadequate vegetative cover. The rate of soil erosion in Lesotho is 41 tons of soil per hectare per year.

The southern part of Lesotho is faced with the problem of desertification due to low annual rainfall, which ranges from 200 to 450 mm. Overstocking more especially of small livestock resulting in overgrazing and rampant trampling that destroys the soil structure. Plowing along steep slopes exacerbates the rate of soil erosion and result in formation of gullies Fig. 8.3. These factors make the soil susceptible to water and wind erosion.

Wind erosion is not well documented but poses a major problem during the months of August and September, when dust storms occur frequently. At times they are capable of blocking the sunlight. However, there are no formations of sand dunes unlike many other areas of the world. Early spring rains quickly wash away the small piles of soil deposited by wind.

Water erosion is a major problem caused by the heavy rainfall which occurs in spring and summer. Due to the topography, highly erosive soils and overgrazing, a lot of topsoil is washed away resulting in formation of gullies, and this drops the water table of the adjacent areas. As a result there is degradation of rangelands and desertification.

Rangelands present the biggest challenge to Lesotho and a serious loss to biodiversity. Lesotho is experiencing a high loss of soil largely as a result of poor

Fig. 8.3 Severe gullying in arable terraces in Lesotho

range management practices. Rangelands are communally used under control of the chieftainship. As mitigation, the government is encouraging the establishment of grazing associations in order to turn rangelands into a common property resource. Each grazing association is given an area (range management area) that it controls. It is believed that because of private gain, livestock owners will tend to manage and use their range management area sustainably. There are big challenges facing this new policy however largely rooted in group dynamics and political will (Fig. 8.4).

The greatest part of the country is purely grassland (Fig. 8.5). Lesotho is not a forested country although it has small isolated pockets of indigenous forests and shrub lands which are mainly within the sheltered valleys in the foothills and the lowlands (Fig. 8.6). These indigenous forests are managed by the chieftainship and used communally for firewood. In order to meet the ever-increasing firewood demand, the government through the Ministry of Forestry and Land Reclamation embarked on afforestation programs. These were in the past focused on planting exotic species such as Pine and Eucalyptus. In recent years however, indigenous species have also been encouraged. Community forestry initiatives have been encouraged including establishment of communal reserves and nurseries. To this extent, most government activities are focused on providing firewood, sawn timber, pole production and protection of land against erosion by relieving excessive over cutting of indigenous trees and shrubs. The only indigenous forest falling under protected area management is found in the Tsehlanyane National Park.

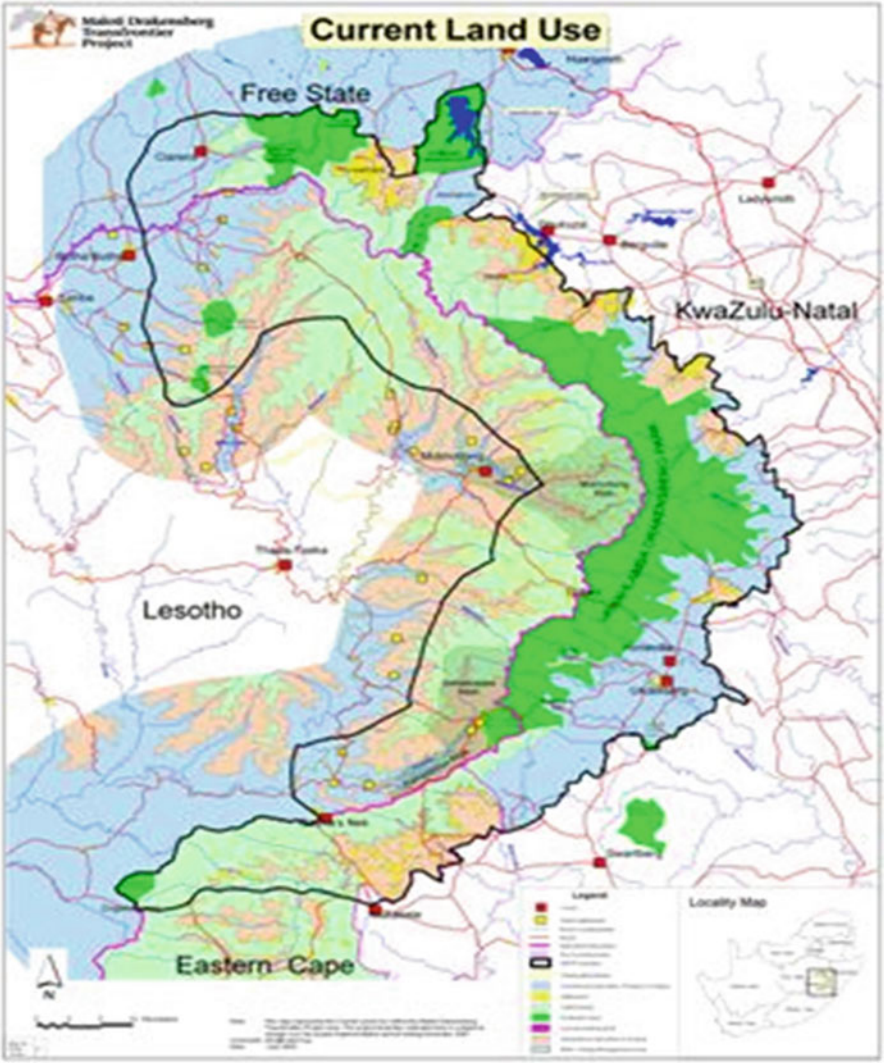


Fig. 8.4 Land use Map. The areas shown in green are the protected areas. Grazing land occupies the biggest area

3 Erosion Control Program in Lesotho

In order to combat desertification and land degradation, Lesotho has recently established the Ministry of Forestry and Land Reclamation. This Ministry is divided into three major departments:

Fig. 8.5 Grass cover in the mountains of Lesotho

Fig. 8.6 Indigenous trees of Lesotho (*Leucosidia sericea*)

1. Forestry Department
2. Soil and Water Conservation Department
3. Range Resources Management Department

Forestry Department: To provide firewood, timber and poles by planting both exotic and indigenous trees with aim to avert over cutting of indigenous trees and shrubs. The annual target: 1.5 Million trees planted of which 45,000 are fruit trees.

Soil Conservation Department: to conserve soil and water and encourage minimum tillage practices

Annual target: Dam construction (7) and Roof water and spring water tank construction (65)

Range management: to train the public on good range management practices and establishment of grazing associations. The annual target is to set up 20 grazing associations/annum and re-seeding 20 grassland areas/annum.

On top of this the Government of Lesotho has engaged integrated watershed management system through the Ministry of Forestry and Land Reclamation (MoFLR), which started in 2002 in a participatory approach (Involvement of Rural Communities).

3.1 Community Participation

For remedial works to control soil erosion being sponsored by governments or other agencies for community operation and management, whether for agriculture or water supply, it is essential to consult local people. Try to obtain a representative view, not just that of landowners or important people in a community, but also those who will be most directly affected or benefit from any dam, to determine their needs and views. This is particularly important where the community is expected to contribute towards the siting and construction (i.e. with the provision of land, their labour and possibly local materials) operation and maintenance of the dam. Responsible ownership of the dam and its catchment by the community, even if the remediation work is to be built by an outside agency, is vital for future maintenance and longevity of the structure.

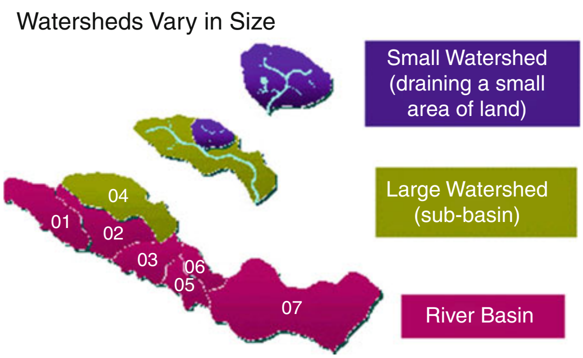
Social and gender issues should be considered at this time and throughout the design and construction process (Fig. 8.7). Men and women differ in their preference and needs for water and will be affected differently when the dam is finished and is storing water. It is important not to constrain the participation of women or the poor in decision making, in membership of groups associated with the dam (and any irrigation scheme) and in evaluating changes that will occur in workloads for men and women following the introduction of the dam and its related infrastructure.

The objectives of the integrated watersheds program is to rehabilitate the heavily degraded areas by:

1. Improvement of range lands
2. Reduction of soil erosion
3. Improvement of water quality
4. Improvement of soil moisture

Fig. 8.7 Showing gender balance in implementation of land rehabilitation activities

Fig. 8.8 A watershed is all the land that water flows across or through on its way to a specific tributary stream, or river . . .



5. Improvement of agricultural production
6. Afforestation for the supply of energy
7. Planting of Fruit-trees

The work in the catchments started in 2002 where one or two catchments were selected in each district and after a year new catchments were selected and worked upon. It was realized that working with micro watersheds yields low positive results and also one year is not enough for a significant healing or rehabilitation process to take place. Therefore in 2005, a decision was made to select bigger watersheds and the rehabilitation program increased to three years in order to realize the impacts (Figs. 8.8 and 8.9).

Fig. 8.9 Watersheds have boundaries and an outlet (mouth). They represent a useful management unit

3.2 Erosion Control Measures in Lesotho

Erosion control measures can be divided into two types, The Mechanical measures and the biological measures. The mechanical are used to stabilize the condition but are temporary and the biological are permanent (see also Chaps. 2 and 3).

3.2.1 Structural Options

Various structural measures can be used depending on the particular requirements of an area. Material like loose stones, bricks, bamboo piles, bamboo mats, stone filled gabions, and sand filled bags are all used. With appropriate support the community can do the bulk of the work including collecting stones, filling the gabions, and earthworks etc. Dykes run along the side of river rather than protruding into the river. They protect the river bank from erosion but do not redirect the river.

3.2.2 Mechanical Measures

1. Stone-lines
   Constructed along the contour line on the slope to trap silt and reduce the runoff speed
2. Pasture furrows
   Constructed without outlet to improve moisture content of the area

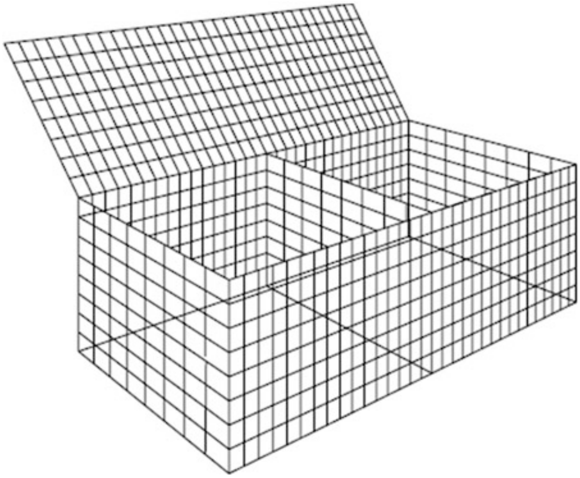


Fig. 8.10 A basic gabion before filling with stones

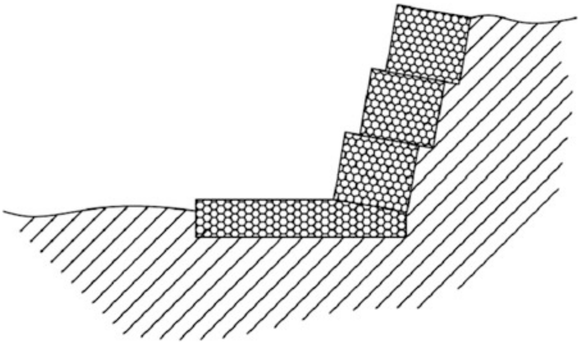


Fig. 8.11 Section through a gabion dyke (stone filled baskets) used to protect stream banks and prevent erosion

3. Diversion furrows
   Constructed to control and direct the flow of water (water way, dam)
4. Terraces
   Constructed in the fields
5. Silt-traps and gabion structures
   Constructed to trap sediment load in the gully and to slow down the speed of runoff
6. Check dams
   Constructed to trap silt and provide temporary supply of water for irrigation and livestock (Figs. 8.10, 8.11, 8.12 and 8.13).

3.2.3 Biological Measures

1. Afforestation
   Willows, Poplars and *Pseudococacia* are planted to stabilize the soil in the gullies (Fig. 8.12)

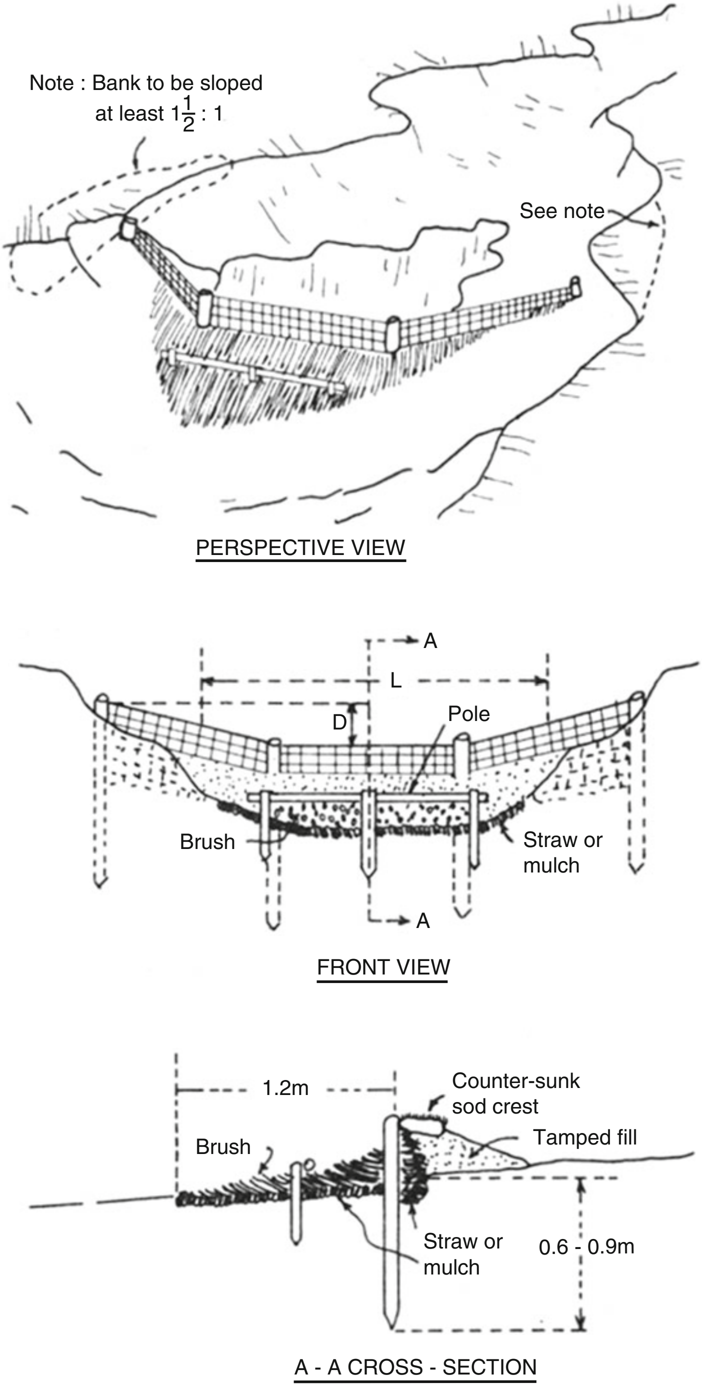


Fig. 8.12 Cross section of gully plug showing details of construction

Fig. 8.13 Shows mechanical measures (Diversion furrow, stone lines and silt-traps respectively)

Fig. 8.14 Public participation in afforestation in Lesotho

2. Grass seeding
   Grasses such as *Eragrostis curvula* are used to reclaim the rangelands
3. Grass sodding
   Grasses such as *Kikuyu* and *Banagrass* are sodded on the dam embarkment for protection and in the gullies (Fig. 8.14).

3.2.4 Other Activities in the Integrated Watershed

1. Water harvesting for small scale irrigation and livestock:

   (a) Roof water Harvesting tanks

Fig. 8.15 Concrete tank to protect a spring. This project provided jobs and taught skills

   (b) Spring/stream development tanks
   (c) Dam construction

2. Beekeeping
3. Establishment of orchards and vine yards
4. Rabbit Rearing (Herders)
5. Promotion and establishment of labour intensive works in order to increase local benefits
6. To treat this particular pilot area as the model for other places within and outside the district
7. Creation of jobs to the villagers by development of cottage and fruit processing industries.

Figure 8.15 is an example of a project involving the local community.

4 Conclusions

Although the recommended target of protected area for each country is 10 %, Lesotho still has less than 1 % as the area under formal protection (Fig. 8.3). This is made up of the Sehlabathebe National Park (SNP), Tsehlanyane National Park (TNP), Bokong Nature Reserve (BNR) and Masitise Nature Reserve (MNR). Some attempts are being made to increase this area. These protected areas do not cover all the significant ecological areas of the country. Many of them are also very small in size. As such they cannot successfully accommodate faunal species that require large territories. There are only two Botanical Gardens in Lesotho. These are the National University of Lesotho (NUL) Garden, which is mainly used for teaching purpose, and the Katse Botanical Garden that was established by the Lesotho Highlands Water Project (LHWP) in 1996. The Katse Botanical Garden is largely focused on alpine vegetation with the emphasis of plants that are heavily used for livelihoods. It has a propagation program for these species so that they could be re-introduced into the wild. This component also reduced pressure from wild species, as communities and individual users purchase from the garden instead of collecting from the wild. Both gardens have housed specimens that were rescued from mountain valleys that are inundated by the LHWP.

These attempts are facilitated by projects that are funded by the Global Environment Facility (GEF), such as the Conservation of Mountain Biodiversity in Southern Lesotho (CMBSL) and the Maloti Drakensberg Transfrontier Project (MDTP). The Maloti-Drakensberg Transfontier Conservation and Development Project (MDTP) is a collaborative initiative between South Africa and the Kingdom of Lesotho to protect the exceptional biodiversity of the Drakensberg and Maloti mountains through conservation, sustainable resource use, and land-use and development planning. This area encompasses distinct landscape and biological diversity. It is quite rich in species and high in endemism. Excessive livestock grazing, crop cultivation on steep slopes, uncontrolled burning, alien invading species and human encroachment threatens this asset. To maintain the ecosystem integrity of these areas and to alleviate poverty in the mountains, the Governments of Lesotho and South Africa have made a joint intervention to arrest these problems through the Maloti-Drakensberg Transfrontier Project.

Lesotho has recently acceded to the Ramsar Convention. It has listed the Letsa-la-Letsie wetland in Quthing district as the wetland of international significance. This wetland is the source of the Quthing River, which is a major tributary of Senqu or the Orange River. The Orange River is one of the largest rivers in Southern Africa. The conservation of wetlands in Lesotho is important especially in the light of the Lesotho Highlands Water Project (LHWP), which harnesses water for sale to South Africa. Water is therefore an important economic asset for Lesotho. Lesotho has ratified the United Nation Convention to Combat Desertification and is already preparing alignment of National Action Program (NAP) with 10 year strategic plan of UNCCD.

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Chapter 9
Desert Environments of Republic of Chad

Hakim Djibril

Synopsis This chapter presents an overview of the current status of desertification in Chad and outlines the measures being taken to arrest and reverse land degradation, revegetate bare land and raise household incomes. The outcomes of several successful projects are summarized.

Key Points

- Like most states of the African Sahel, Chad has suffered from the encroachment of the desert. Traditional herding practices and the need for firewood and wood for construction have exacerbated the problem. Lake Chad was one of the largest fresh bodies of water on the African continent and its disappearance will have a tremendous impact on the population surrounding it. The problem of Lake Chad is increasingly complex because of the international nature of the desertification. Lake Chad is a regional problem East African and North African member states of the African Union and UN must deal with it. A collaborative approach to combating the desertification of Lake Chad is needed to reverse the current trends.
- Land and terrestrial resources in Africa have unparalleled economic, social and environmental value. Traditionally, African societies are agrarian or pastoral, depending directly on subsistence farming to meet their daily needs. Commercial agriculture holds an equally important position, employing the largest share of the workforce in most countries, and contributing significantly to national economic growth, export earnings and foreign exchange. However, national and household dependency on agricultural output has been a significant factor in limited economic growth over the past three decades. Climatic instability

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has caused significant and frequent variability in production, and narrow crop diversity, and national and international market failures, have facilitated recurrent economic losses.

- Desertification, land degradation and drought have negative impact on the availability, quantity and quality of water resources that result in water scarcity. As desertification takes its toll, water crises are expected to continue raising ethnic and political tensions in drylands, contributing to conflicts where water resources straddle or delineate country borders. Water scarcity is the long-term imbalance between available water resources and demands. Increasing occurrences of water scarcity, whether natural or human-induced, serve to trigger and exacerbate the effects of desertification through direct long-term impacts on land and soil quality, soil structure, organic matter content and ultimately on soil moisture levels.
- The direct physical effects of land degradation include the drying up of freshwater resources, an increased frequency of drought and sand and dust storms, and a greater occurrence of flooding due to inadequate drainage or poor irrigation practices. Should this trend continue, it would bring about a sharp decline in soil nutrients, accelerating the loss of vegetation cover. This leads in turn to further land and water loss from pollution of surface and groundwater, siltation, salinization, and alkalization of soils. Poor and unsustainable land management techniques also worsen the situation. Over cultivation, overgrazing and deforestation put great strain on water resources by reducing fertile topsoil and vegetation cover, and lead to greater dependence on irrigated cropping. Observed effects include reduced flow in rivers that feed large lakes such as Lake Chad, leading to the alarmingly fast retreat of the shorelines of these natural reservoirs in Chad. With climate change, the situation is likely to get worse – less water and creeping desertification in the semi-arid terrain.
- Declining productivity and soil structure in the Sahelian zones of Chad is exacerbated by unpredictable rainfall and drought, resulting in extreme degradation and desertification. Chad is currently experiencing the greatest vulnerability to desertification, with 58 % of the area already classified as desert, and 30 % classified as highly or extremely vulnerable.
- Rapid population growth and policy pressures to increase production have forced the cultivation of greater and greater areas of land in all sub-regions, and the extension of cultivation and grazing to marginal areas. Combined with limited application of organic or inorganic fertilizers, reductions in fallow periods, restrictions on crop diversity, inappropriate irrigation, and an increasing use of herbicides and pesticides, this has resulted in the physical, chemical and biological degradation of vegetation and soil. Soil erosion and desertification rates are increasing as a result, and declines in productivity have been noted.

Keywords Dust storms • Wildlife • Biodiversity • Shelter belt • Oasis • Camels • Poverty • Ostriches • Lake Chad • Palms • Great Green Wall • Poverty • Armed conflict • Food insecurity • Ethnic tensions

1 Introduction

Located in north-central Africa, Chad stretches for about 1,800 km from its northern most point to its southern boundary. Except in the far northwest and south, where its borders converge, Chad's average width is about 800 km. Its area of 1,284,000 km^2 is roughly equal to the combined areas of Idaho, Wyoming, Utah, Nevada, and Arizona. Chad's neighbors include Libya to the north, Niger and Nigeria to the west, Sudan to the east, Central African Republic to the south, and Cameroon to the southwest (Fig. 9.1). Chad exhibits two striking geographical characteristics.

Fig. 9.1 Map of Chad showing its location as a land-locked country located on the fringe of the Sahara desert

First, the country is landlocked. N'Djamena, the capital, is located more than 1,100 kilometers (km) inland from the Atlantic Ocean; Abéché, a major city in the east, lies 2,650 km from the Red Sea; and Faya Largeau, a much smaller but strategically important center in the north, is in the middle of the Sahara Desert, 1,550 km from the Mediterranean Sea. These vast distances from the sea have had a profound impact on Chad's historical and contemporary development. The second noteworthy characteristic is that the country borders on very different parts of the African continent: North Africa, with its Islamic culture and economic orientation toward the Mediterranean Basin; West Africa, with its diverse religions and cultures and its history of highly developed states and regional economies; Northeast Africa, oriented toward the Nile Valley and Red Sea region; and Central or Equatorial Africa, some of whose people have retained classical African religions while others have adopted Christianity, and whose economies were part of the great Zaire River system. Although much of Chad's distinctiveness comes from this diversity of influences, since independence the diversity has also been an obstacle to the creation of a national identity.

2 Geography, Climate and Land Use

2.1 General Geography

Three climate regions make up the majority of the country – a desert in the north, an arid region in the center, and a tropical area in the south. Lake Chad is located on the western border and is an important source of water for Chad and surrounding countries. Although Chadian society is economically, socially, and culturally fragmented, the country's geography is unified by the Lake Chad Basin. Once a huge inland sea (the Pale-Chadian Sea) whose only remnant is shallow Lake Chad, this vast depression extends west into Nigeria and Niger. The larger, northern portion of the basin is bounded within Chad by the Tibesti Mountains in the northwest, the Ennedi Plateau in the northeast, the Ouaddaï Highlands in the east along the border with Sudan, the Guéra Massif in central Chad, and the Mandara Mountains along Chad's southwestern border with Cameroon. The smaller, southern part of the basin falls almost exclusively in Chad. It is delimited in the north by the Guéra Massif, in the south by highlands 250 km south of the border with Central African Republic, and in the southwest by the Mandara Mountains.

Lake Chad, located in the southwestern part of the basin at an altitude of 282 m above sea level (a.s.l.), surprisingly does not mark the basin's lowest point; instead, this is found in the Bodele and Djourab regions in the north-central and northeastern parts of the country, respectively. This oddity arises because the great stationary dunes (*ergs*) of the Kanem region create a dam, preventing lake waters from flowing to the basin's lowest point. At various times in the past, and as late as the 1870s, the Bahr el Ghazal Depression, which extends from the northeastern part of the lake to the Djourab, acted as an overflow canal; since Independence in 1960, climatic conditions have made overflows impossible.

North and northeast of Lake Chad, the basin extends for more than 800 km, passing through regions characterized by great rolling dunes separated by very deep depressions. Although vegetation holds the dunes in place in the Kanem region, farther north they are bare and have a fluid, rippling character. From its low point in the Djourab, the basin then rises to the plateaus and peaks of the Tibesti Mountains in the north. The summit of this formation – as well as the highest point in the Sahara Desert – is Emi Koussi, a dormant volcano that reaches 3,414 m a.s.l. The basin's northeastern limit is the Ennedi Plateau, whose limestone bed rises in steps etched by erosion.

East of the lake, the basin rises gradually to the Ouaddaï Highlands, which mark Chad's eastern border and also divide the Chad and Nile watersheds. Southeast of Lake Chad, the regular contours of the terrain are broken by the Guéra Massif, which divides the basin into its northern and southern parts.

South of the lake lie the floodplains of the Chari and Logone rivers, much of which are inundated during the rainy season. Farther south, the basin floor slopes upward, forming a series of low sand and clay plateaus, called *koros*, which eventually climb to 615 m a.s.l. south of the Chadian border, the *koros* divide the Lake Chad Basin from the Ubangi-Zaire river system.

2.2 Rivers

Chad's major rivers are the Chari and the Logone and their tributaries, which flow from the southeast into Lake Chad. Both river systems rise in the highlands of Central African Republic and Cameroon, regions that receive more than 1,250 millimeters (mm) of rainfall annually. Fed by rivers of Central African Republic, as well as by the Bahr Salamat, Bahr Aouk, and Bahr Sara rivers of southeastern Chad, the Chari River is about 1,200 km long. From its origins near the city of Sarh, the middle course of the Chari makes its way through swampy terrain; the lower Chari is joined by the Logone River near N'Djamena. The Chari's volume varies greatly, from 17 cubic meters per second (cusecs) during the dry season to 340 cusecs during the wettest part of the year.

The Logone River is formed by tributaries flowing from Cameroon and Central African Republic. Both shorter and smaller in volume than the Chari, it flows northeast for 960 km; its volume ranges from five to eighty-five cusecs. At N'Djamena the Logone empties into the Chari, and the combined rivers flow together for 30 km through a large delta and into Lake Chad. At the end of the rainy season in the Fall, the river overflows its banks and creates a huge floodplain in the delta.

The seventh largest lake in the world (and the fourth largest in Africa), Lake Chad is located in the *sahelian* zone, a region just south of the Sahara Desert. The Chari River contributes 95 % of Lake Chad's water, an average annual volume of 40 billion cubic meters, 95 % of which is lost to evaporation. The size of the lake is determined by rains in the southern highlands bordering the basin and by temperatures in the Sahel. Fluctuations in both cause the lake to change dramatically in size, from 9,800 km^2 in the dry season to 25,500 km^2 at the end of the rainy season. Lake Chad also changes greatly in size from one year to another. In 1870 its maximum area was 28,000 km^2. The measurement dropped to 12,700 in 1908. In the 1940s and 1950s, the lake remained small, but it grew again to 26,000 km^2 in 1963. The droughts of the late 1960s, early 1970s, and mid-1980s caused Lake Chad to shrink once again (Coe and Foley 2001). The only other lakes of importance in Chad are Lake Fitri, in Batha Prefecture, and Lake Iro, in the marshy southeast.

2.3 Climate

The Lake Chad Basin embraces a great range of tropical climates from north to south, although most of these climates tend to be dry. Apart from the far north, most regions are characterized by a cycle of alternating rainy and dry seasons. In any given year, the duration of each season is determined largely by the positions of two great air masses–a maritime mass over the Atlantic Ocean to the southwest and a much drier continental mass. During the rainy season, winds from the southwest push the moister maritime system north over the African continent where it meets and slips under the continental mass along a front called the ITCZ (intertropical convergence zone). At the height of the rainy season, the front may reach as far as Kanem Prefecture. By the middle of the dry season, the ITCZ moves south of Chad, taking the rain with it. This weather system contributes to the formation of three major regions of climate and vegetation.

3 The Saharan Desert System

3.1 Sahara Region

The Saharan region covers roughly the northern third of the country, including Borkou-Ennedi-Tibesti Prefecture along with the northern parts of Kanem, Batha, and Biltine prefectures. Much of this area receives only traces of rain during the entire year; at Faya Largeau, for example, annual rainfall averages less than three centimeters. Scattered small oases and occasional wells provide water for a few date palms or small plots of millet and garden crops. In much of the north, the average daily maximum temperature is about 32 °C during January, the coolest month of the year, and about 45 °C during May, the hottest month. On occasion, strong winds from the northeast produce violent sandstorms. In northern Biltine Prefecture, a region called the Mortcha plays a major role in animal husbandry. Dry for 9 months of the year, it receives 350 mm or more of rain, mostly during July and August. A carpet of green springs from the desert during this brief wet season, attracting herders from throughout the region who come to pasture their cattle and camels. Because very few wells and springs have water throughout the year, the herders leave with the end of the rains, turning over the land to the antelopes, gazelles, and ostriches that can survive with little surface water.

3.2 Sahelian Region

The semiarid *sahelian* zone, or Sahel, forms a belt about 500 km wide that runs from Lac and Chari-Baguirmi prefectures eastward through Guéra, Ouaddaï, and northern Salamat prefectures to the Sudanese frontier. The climate in this transition zone between the desert and the southern *soudanian* zone is divided into a rainy season (from June to early September) and a dry period (from October to May). In the northern Sahel, thorny shrubs and *acacia* trees grow wild, while date palms, cereals, and garden crops are raised in scattered oases. Outside these settlements, nomads tend their flocks during the rainy season, moving southward as forage and surface water disappear with the onset of the dry part of the year. The central Sahel is characterized by drought-resistant grasses, shrubs and low trees. Rainfall is more abundant there than in the Saharan region. For example, N'Djamena records a maximum annual average rainfall of 580 mm, while Ouaddaï Prefecture receives just a bit less. During the hot season, in April and May, maximum temperatures frequently rise above 40 °C. In the southern part of the Sahel, rainfall is sufficient to permit crop production on unirrigated land, and millet and sorghum are grown. Agriculture is also common in the marshlands east of Lake Chad and near swamps or wells. Many farmers in the region combine subsistence agriculture with the raising of cattle, sheep, goats, and poultry.

3.3 Soudanian Region

The humid *soudanian* zone includes the southern prefectures of Mayo-Kebbi, Tandjilé, Logone Occidental, Logone Oriental, Moyen-Chari, and southern Salamat. Between April and October, the rainy season brings between 750 and 1,250 mm of precipitation. Temperatures are high throughout the year. Daytime readings in Moundou, the major city in the southwest, range from 27 °C in the middle of the cool season in January to about 40 °C in the hot months of March, April, and May.

The *soudanian* region is predominantly savanna, or plains covered with a mixture of tropical or subtropical grasses and woodlands. The growth is lush during the rainy season but turns brown and dormant during the 5-month dry season between November and March. Over a large part of the region, however, natural vegetation has yielded to cropland.

4 Environmental Protection

With two national parks, five game reserves, and one Wetland of International Importance, 9 % of Chad's natural areas are protected. The chief environmental problem is increasing desertification after a decade marked by below-normal rainfall and periodic droughts. Warring factions in Chad have damaged the environment and hampered the efforts of the government to address environmental problems for 25 years. Locust swarms periodically cause crop damage. The availability of fresh water is also a major problem. Safe drinking water is available to 31 % of urban dwellers and 26 % of the rural population. About 82 % of the nation's renewable water resources are used for farming activity.

Elephant herds were reported greatly decimated in the 1970s. As of the 2000, endangered species in Chad included the black rhinoceros, Dallon's gerbil, and African wild ass. The Sahara oryx, also called the scimitar-horned orynx, is extinct in the wild. Of 134 species of mammals in Chad, 14 are threatened with extinction. Three bird species out of 370 are also threatened. One reptile out of five and five plant species out of 1,600 are in danger of extinction. In 1986 approximately 83 % of the active population were farmers or herders. This sector of the economy accounted for almost half of GDP. With the exception of cotton, some small-scale sugar production, and a portion of the peanut crop, Chad's agriculture consisted of subsistence food production. The types of crops that were grown and the locations of herds were determined by considerable variations in Chad's climate.

5 Land Use

As with most Third World countries, control of the land determines agricultural practices. There are three basic types of land tenure in Chad. The first is collective ownership by villages of croplands in their environs. In principle, such lands belong to a village collectively under the management of the village chief or the traditional *chef des terres* (chief of the lands). Individual farmers hold inalienable and transmittable use rights to village lands, so long as they, their heirs, or recognized representatives cultivate the land. Outsiders can farm village lands only with the authorization of the village chief or *chef des terres*. Renting village farmlands is possible in some local areas but is not traditional practice. Private ownership is the second type of tenure, applied traditionally to the small plots cultivated in wadis or oases. Wells belong to individuals or groups with rights to the land. Ownership of fruit trees and date palms in the oases is often separate from ownership of the land; those farmers who plant and care for trees own them. State ownership is the third type, primarily for large enterprises such as irrigation projects. Under the management of parastatal or government employees, farmers enter into contractual arrangements, including paying fees, for the use of state lands and the benefits of improved farming methods.

The *soudanian* zone comprises those areas with an average annual rainfall of 800 mm or more. This region, which accounts for about 10 % of the total land area, contains the nation's most fertile croplands. Settled agricultural communities growing a wide variety of food crops are its main features. Fishing is important in the rivers, and families raise goats, chickens, and, in some cases, oxen for plowing. In 1983 about 72 % of all land under cultivation in Chad was in the *soudanian* region.

The central zone, the *sahelian* region, comprises the area with average annual rainfall of between 350 and 800 mm. The minimum rainfall needed for the hardiest of Chad's varieties of millet, called *berebere*, is 350 mm. The western area of the zone is dominated by the Chari and Logone rivers, which flow north from their sources in southern Chad and neighboring countries. The courses of these rivers, joining at N'Djamena to flow on to Lake Chad, create an ecological subregion. Fishing is important for the peoples along the rivers and along the shores of Lake Chad. Flood recession cropping is practiced along the edges of the riverbeds and lakeshore, areas that have held the most promise for irrigation in the zone. International donor attention focused on this potential beginning in the mid-1960s. Particular attention has been paid to the traditional construction of polders along the shores of Lake Chad. Land reclaimed by the use of such methods is extremely fertile. Chad's only wheat crop is cultivated in these polders.

In the rest of the *sahelian* region, the hardier varieties of millet, along with peanuts and dry beans, are grown. Crop yields are far lower than they are in the south or near rivers and lakes. Farmers take every advantage of seasonal flooding to grow recession crops before the waters dry away, a practice particularly popular around Lake Fitri. The *sahelian* region is ideal for pasturage. Herding includes large cattle herds for commercial sale, and goats, sheep, donkeys, and some horses are common in all villages.

The Saharan zone encompasses roughly the northern one-third of Chad. Except for some dates and legumes grown in the scattered oases, the area is not productive. Annual rainfall averages less than 350 mm, and the land is sparsely populated by nomadic tribes. Many of Chad's camel herds are found in the region, but there are few cattle or horses.

6 Agriculture

Production systems in the Saharan region are characterized by an agro-forestry system that centers on the *wadis* and palms. Date palm cultivation, irrigated subsistence farming, sedentary rearing of small ruminants and nomadic camel rearing are all practised.

Fig. 9.2 Local livestock owners of livestock practice transhumance to chase the seasonal availability of forage and water

6.1 Sahelian Region

Production systems in the Sahelian region are a combination of diversified systems dominated by pastoral agro-forestry. Agricultural practices range from traditional irrigated subsistence farming to a more viable extensive farming of oilseeds and legumes. Although vegetation in the south includes trees and forests, the north is more steppe-like. Forests are exploited essentially for ligneous products for domestic energy needs and economically profitable ligneous sub-products, in particular gum arabic. Animal rearing is transhumant (Fig. 9.2).

6.2 Sudano Region

Production systems in the Sudano region are very diversified. Vegetation consists of dry dense forests and savannah. These lands are used for cattle-rearing and cereal, oilseed, tuber, legume and cotton production.

Chad's subsistence farmers practice traditional slash-and-burn agriculture in tandem with crop rotation, which is typical throughout much of Africa. Sorghum is the most important food crop, followed by millet and *berebere*. Less prevalent grains are corn, rice, and wheat. Other secondary crops include peanuts, sesame, legumes, and tubers, as well as a variety of garden vegetables.

Crop rotation in the *soudanian* zone traditionally begins with sorghum or millet in the first year. Mixed crops of sorghum and/or millet, with peanuts, legumes, or tubers, are then cultivated for approximately 3 years. Farmers then return the land to fallow for periods up to 15 years, turning to different fields for the next cycle. Preparation of a field begins with cutting heavy brush and unwanted low trees or branches that are then laid on the ground. Collectively owned lands are parceled out during the dry season, and the fields are burned just before the onset of the first rains, usually around March. Farmers work most intensively during the rains between May and October, planting, weeding and protecting the crops from birds and animals. Harvesting begins in September and October with the early varieties of sorghum. The main harvest occurs in November and December. Farmers harvest crops of rice and *berebere*, grown along receding water courses, as late as February.

The cropping cycle for most of the *sahelian* zone is similar, although the variety of crops planted is more limited because of dryness. In the polders of Lake Chad, farmers grow a wide range of crops; two harvests per year for corn, sorghum, and legumes are possible from February or March to September. Rice ripens in February, and wheat ripens in May.

Detailed and reliable statistical information on Chad's agriculture was scarce in the late 1980s; most researchers viewed available statistics only as indicators of general trends. The one region for which figures were kept was the *soudanian* zone through survey coverage by officials of the National Office of Rural Development (Office National de Développement Rural–ONDR), who monitored cotton production. These officials also gathered information on food production, but this effort was not carried out systematically. Survey coverage of the *sahelian* zone was first hampered, then prevented, by civil conflict from the mid 1970s to the early 1980s.

Moreover, figures from international and regional organizations often conflicted or differed in formulation. For example, total area devoted to food production was difficult to estimate because sources combined the area of fields in production with those lying fallow to give a total for arable lands. The arable land figure has shown a gradual increase since 1961. Estimated then at 2.9 million hectares (Mha), it rose to almost 3.2 Mha in 1984. In 1983 there were about 1.2 Mha in food production and in 1984 slightly more than 900,000 ha. Therefore, perhaps a third of Chad's farmlands were in production in a given year, with the balance lying fallow.

7 Desertification in Chad: Causes and Consequences

Land degradation and dwindling water resources are caused by over-exploitation of natural resources to satisfy daily food and energy requirements, as well as climate change. Food production systems based on unsustainable practices and the removal of wood for fuel are among the issues that must be addressed. A lack of arable land due to desertification, coupled with limited access to water and healthcare, has had devastating effects on malnutrition rates in the region. Food insecurity is a major problem.

8 Demography and Population Movements

The impact of climate degradation on Chad's ecosystems is accentuated by the pressure exerted on the environment by Chad's strong demographic growth (2.5 % per year). Migratory movements that occur under the combined effects of war and drought have, moreover, profoundly modified the socio-economic equilibrium. The social structure of herder-farmers has been disturbed The presence and sometimes settlement of rearer-herders in certain areas has brought about tensions with farmers Encouraging rearer-herders to shift to farming activities has not been achieved without social problems as new agricultural lands need to be found for these people.

9 Desert Encroachment Problems

Like most states of the African Sahel, Chad has suffered from the encroachment of the desert. Today, the phenomenon of desertification affects the entire country of Chad. However, the most affected areas are located between 12° and 22° north latitude, covering an area of 1,091,420 km^2 approximately 85 % of the country.

Traditional herding practices and the need for firewood and wood for construction have exacerbated the problem. In the early 1980s, the country possessed between 13.5 and 16 Mha of forest and woodlands, representing a decline of almost 14 % from the early 1960s. To what extent this decline was caused by climatic changes and to what extent by herding and cutting practices was unknown. Regulation was difficult because some people traditionally made their living selling wood and charcoal for fuel and wood for construction to people in the urban center. Although the government attempted to limit wood brought into the capital, the attempts have not been well managed, and unrestricted cutting of woodlands remains a problem.

10 Combating Desertification and Controlling Desert Encroachment

These twin problems are inextricably linked in Chad in the same way that they are seen in many of the case studies in this book. The original thinking about desertification was that it represented as "a process of drying which turns previously productive areas into areas classically defined as desert or wasteland". Later, the concept morphed into something more general like "degradation of formerly productive land through a combination of human-induced and climatic factors" (see Chap. 1). 'Fighting the desert' is a recurring theme in many of the case studies presented here.

National Program of Action to Combat Desertification (PAN/LCD). The Program of Action defines a framework of measures to assist people and local organizations in securing a sustainable improvement in dryland management. It identifies factors contributing to desertification and concrete measures to combat it and mitigate the effects of drought. It is to incorporate long-term strategies to combat desertification and be integrated with national policies on sustainable development.

One of the most pressing issues for Chad is the rate of desertification due to deforestation, inappropriate farming techniques and crop selection. In fact, the country is experiencing environmental problems. The main ones are:

- Encroachment of sands into oases and croplands
- Lack of soil protection and regeneration and an absence of an agency to coordinate water and soil conservation;
- Inadequate nature conservation measures and the failure to implement existing regulation

11 Political and Strategic Considerations

Because of political instability and subsequent clashes, which have occurred at the same time as periods of drought, Chad has been unable to implement a real strategy to combat desertification to the extent of other Sahelian countries. Although activities have been undertaken within the general framework of combating desertification, they tended to be aimed at improving the environment (the green belt of N'djamena) or promoting agricultural production (*Acacia albida, Karité*) or forest production (*Acacia senegal*). In all cases, these projects were instigated by the forestry service, or under its auspices, and their objectives were essentially sectoral.

Furthermore, these actions were too limited in terms of both their time frames and the affected land areas to have any significant impact on the desertification process. In a significant number of cases, they did not achieve their sectoral objectives. Because of this, it became apparent that, if Chad was to be successful in fighting desertification, there was a need to implement a rational and consistent strategy; drawing on accumulated experience and a more objective analysis of the situation It was determined that this strategy should be inspired by the regional structure outlined in the Nouakchott strategy (CILSS 1994), and should be translated at the national level by a General Plan to Combat Desertification (*Plan directeur de lutte contre la désertification*, or PDLCD). The PDLCD would need to analyze the process of desertification, define directions in line with development options, put forward a strategy and, finally, propose an action program. In brief, it would guide actions, in view of proposing solutions better adapted to the specific problems of desertification in Chad.

Desertification control is a major component of Chad's national environmental protection. The national action plan to combat desertification (PDLCD) has the following strategic orientation:

- Transferring natural resource management responsibilities to rural communities
- Awareness raising and information, training and extension work;
- Promoting environment-friendly;
- Protecting and regenerating environmental resources;
- Improving production systems;
- Establishing an institutional framework (see below).

The Chadian government elaborated and adopted the PDLCD in 1989. The strategic orientations of the PDLCD hinge on the following four major axes:

- Transferring responsibilities for the management of natural resources to the rural community: this must be translated at the judicial level, notably as concerns tax laws, by a thorough reform of government's hitherto centralized approach. The sectoral session of 1994 thus announced that rural communities would be involved in the management of natural resources, in particular through a 'decentralization of responsibilities' within the framework of village land management.
- Promoting public awareness by disseminating information and provision of training as the principal means of involving the population.
- Promoting use of production systems that do not consume natural resources. This involves choosing appropriate, cost-efficient regions in which to operate the careful selection of resources, while monitoring natural resources and increasing public understanding of them.
- Establishing an organizational structure that promotes inter-sectorality and the integration of rural/environment development and is centered on adapting existing structures and projects rather than on introducing specific environmental structures.

12 Case Studies of Projects Designed to Arrest and Reverse Desertification

12.1 Case Study: Combating Sand Encroachment in Kanem

The area covered by this study, the Kanem, covers 115,000 km^2 and has a population of 280,000 people. As have other Sahara and Sahel regions, the natural environments of Kanem has suffered degradation in the past few decades, due to the prolonged drought periods that have ruthlessly affected the country since the 1960s, and continue to affect it.

Sand encroachment in Kanem is the most spectacular of the causes of desertification in the region. Currently, sand encroachment affects 64 % of the land and threatens the livelihood of 14 % of the population of Chad. Primarily caused by human activities, other natural factors, such as drought, compound its effects. The considerable scale of the phenomenon is such that the means mobilized by the population have not proven sufficient to protect the region's important infrastructures (inhabited villages, farmed and grazing areas, wells). It has largely been due to government mobilization and the assistance of NGOs that a number of villages (such as Tarfey, Rig-Rig and Barra) and certain *wadis* (Miou, Barkadroussou, Moto) have been saved from being engulfed by sand. The successful actions implemented by the pilot Kanem Agro-Forestry Pastoral Development Project can be used as a model for future interventions against sand encroachment in arid and semi-arid zones. The principal causes are the following: persistent drought, overgrazing, cattle tramping, deforestation and relentless tree logging (evaluated at 250,000 tonnes in 1988), and farming on sand dunes (rendering the dune surface vulnerable to the erosive effects of the wind). In fact, 219 villages, 324 *wadis* and numerous boreholes and grazing areas are increasingly becoming so threatened by sand encroachment as to be potentially life threatening for the local population in Kanem.

The strategy used to fight desertification in Kanem hinges on the following four imperatives:

- The protection of threatened sites and the regeneration of ecological resources
- The improvement of production systems
- The reinforcement of institutional capacities
- The development of a national scheme of land planning

It is within the framework of this combat strategy that the agro-forestry pastoral development project in operation in Kanem from 1993 to 1998 contributed to saving certain villages, *wadis*, schools and clinics from the catastrophe of sand encroachment. Both structural and biological methods were used to halt sand encroachment.

12.2 Structural Methods of Inhibiting Sand Encroachment

12.2.1 Brush Fences

Fencing consists of setting up a barrier (using date palms, *Leptadenia* branches, thorny twigs and millet thatch) between the source of the sand and the threatened area. As sand accumulates along this barrier, it forms an artificial dune, which itself acts as a further obstacle. The fence is placed 200–300 m from the site to be protected, orientated perpendicular to the dominant wind direction.

The following characteristics are required for the success of this approach:

The fence must have a certain permeability, to prevent the wind from destroying it. The only criteria used is the quantity of material used: an average of 20–25 palms or 4–6 branches of *Leptadenia* is used per meter;

- Taking into account sand distribution along the fence according to wind flux, the ideal height of the fence is between 1.5 and 1.8 m;

- Resistance: the greater the height of the fence, the lower its resistance. In building the fence, a trench at least 30 cm deep is needed to firmly sink the supporting elements of the fence. Similarly, these fence elements should be firmly tied together between at two or more levels along the length of the fence to increase its resistance.

This fencing technique has been shown to be very effective in Kanem, especially as the wind is unidirectional (NE–SW). If the opposite is the case, a network of different meshes would be required. As the fence will eventually be engulfed by sand, its height will need to be increased once the sand has reached within 10–15 cm of the top of the fence.

12.2.2 Hedges

After stabilizing sand by mechanical means, it is essential to fix the dunes definitively by promoting vegetation growth. The final aim is to recreate the ecosystem as it existed in the past, which means to conquer land degradation and shifting sands by covering them with as dense a vegetation as possible.

The choice of forest species and local and exotic grasses for biological fixation depends on the capacities of the species to adapt to this environment (its aridity and soil structure). The best adapted local species are *Acacia spp, Balanites aegyptiaca, Leptadenia pyrotechnica, Ziziphus mauritiana* and *Panicum turgidum.* Exotic species that are also well adapted include *Prosopis chilensis, Prosopis juliflora, Parkinsonia aculeata* and *Cajanus cajan*.

Taking into consideration the intensity of sand encroachment in Kanem, biological fixation of shifting dunes is technically only possible with planted species grown in nurseries. The production of plants relies on, among other things, harvesting seeds, choosing an appropriate site and training nursery growers. Work should begin in January each year and terminate in August. Plants grown in the nurseries should be healthy and vigorous, with a height of 50–80 cm. They should be planted out in mid-July, or as soon as soil humidity reaches a depth of 30–40 cm, at a density of 400 plants per hectare — to minimize the cost of the operation and to limit competition between plants, thus favoring natural regeneration.

12.3 Involving the Local Population

The results over the course of the six-year experiment were very encouraging. The method of intervention (using a participatory approach) was based on a contractual agreement between local people and project organizers. The nature of the relationship, the reciprocal engagement and the working methods were written up into a standard contract defining the terms of agreement between the two parties. Agreement to the terms of the contract reflected the two parties shared responsibility. Any community wishing to subscribe to a contract to combat sand encroachment must first organize itself into a united group, which becomes the principal actor in the project. As a result of numerous public-awareness campaigns in recent years, women often find themselves as frontline players in terms of their contribution to agricultural production activities and to the rehabilitation of deforested areas in outlying villages (establishing plant nurseries, constructing fences, planting and maintaining trees, etc.).

12.4 Socio-economic Impacts of the Kanem Project

As well as the immediate ecological and technical impacts achieved by the agro-forestry pastoral development project in Kanem (19 villages have been stabilized, 42 *wadis* have been protected by constructing brush fences, planting live fences and setting up windbreaks, and vegetation has been successfully introduced on 71.5 ha of bare land and moving dunes), the socio-economic impacts of the project have been encouraging. Among these impacts are the recuperation of agricultural and pasturelands in villages and *wadis* that were otherwise abandoned to sand dunes and which are now being farmed. Small mammal (hares and other rodents) long since disappeared from the landscape are returning to these regions.

The development project has then contributed significantly to the local economy. The seasonal rural exodus towards large urban centres such as N'djamena, Moundou and Sarh, or neighbouring countries (Saudi Arabia, Sudan, and Libya) has diminished significantly as local people have become increasingly involved in constructing fences and rehabilitating dunes. Actions to combat sand encroachment are often instigated in Kanem either in response to a state of urgency (e.g. in Tarfey) or through short-term projects with often very limited funds. In the absence of a global program integrating the whole of the ecosystem, these actions have generally been localized one-off projects with limited goals, essentially aimed at combating the encroaching dune fronts. Future studies should be orientated towards elaborating (replication and scaling-up) as part of the PDLCD and combat sand encroachment and integrating a national scheme of land planning and development projects at the regional level, based on a systematic approach and careful analysis of the economic feasibility of projects. The participation of local populations through the provision of incentive measures and the involvement of local authorities is essential to the success of these projects (see also Box 9.1).

Box 9.1: Wind Erosion Control in Bokoro

Wind erosion is a problem and each year seedlings are abraded and arable land is lost to encroachment by sand. The creation of boscages — barriers made up of hedging and trees — using species that are resistant to or adapted to drought conditions and aridity is a potential and feasible action for local farmers to take.

(continued)

Box 9.1 (continued)

In an effort to control such damage the following treatments were applied:

1. Simple scarification followed by direct sowing of sorghum (the staple crop).
2. Earthen ridging was constructed, with seeds sown on the ridges.
3. Earthen ridging was constructed, with seeds sown in the furrows.

The crop planted was a local variety of sorghum: 'Kourtofan'. The seeds were sown in rows 60 cm apart, with one seed every 40 cm in plots that were protected by windbreak hedges comprised of nursery-raised seedlings about 20 months old and 1 m high that were planted in rows at regular 1-m intervals around the perimeter. Crop yields in protected fields were higher and survival of sorghum seedlings was enhanced. It took several years for the hedges to become fully effective. Barriers made up of hedging and trees — using species that are resistant to or adapted to drought conditions and aridity is a potential and feasible action for local farmers to take to protect the crop seedling from the encroaching sand and from being scorched by hot sand particles. It is possible to restore degraded land, even severely degraded land, by employing inexpensive and accessible methods.

Box 9.2: Summary of Ennedi Project in Northern Chad

In the Ennedi region, of northern Chad there was a Swiss government-supported project to protect the oases from desert encroachment. The global objective of the program is the improvement, perpetuation and wider resonance of local activities aimed at combating desertification, and the development of relations and consultation between the relevant actors and the National Office for the Struggle against Desertification, in order to consolidate and strengthen the measures. The initial results of this support are encouraging. They demonstrate the awareness of the local players and their commitment to the need to combat desertification:

– More than 14,000 m of palisades woven with palms have been constructed along the wind corridors.
– The soil contaminated by sand has been reclaimed and put to good use by the owners. Some 150 date seedlings have been planted on the soil freed from the sand dunes.
– The protection and regeneration of vegetation have allowed the ground water to be recharged.

The international donor and NGO community in conjunction with the Chadian government, are addressing the effects of climate change with programs aimed at better management of dwindling water resources and at holding back the spread of desertified land by planting trees in one of the driest and hottest countries on earth.

The Chadian Environment agency inaugurated a national data collection center in 2001 to compile statistics on desertification in the country. The center, a unit of the Agency for Domestic Energy and the Environment, has ended its pilot phase and it was intended for monitoring a 200 km radius around the capital N'djamena.

Lake Chad was one of the largest fresh bodies of water on the African continent and its disappearance will have a tremendous impact on the population surrounding it. The problem of Lake Chad is increasingly complex because of the international nature of the desertification (Coe and Foley 2001). Lake Chad is a regional problem East African and North African member states of the African Union and the UN must deal with it. A collaborative approach to combating the desertification of Lake Chad is needed to reverse the current trends. Projects centered on Lake Chad's desertification reversal highlights an important aspect of the climate change issue. The treatment of symptoms will not solve the larger problem of global climate change. It will take the efforts of people thousands of kms away in a combined effort to combat the global climate change. The improvement of the global condition will make it easier to accomplish the difficult task of desertification reversal but some of the initiatives already in effect (Boxes 9.1, 9.2, 9.3 and 9.4) can do much to arrest and reverse desertification.

Box 9.3: Great Green Wall to Stop Sahel Desertification

The wall envisioned by 11 African countries on the southern border of the Sahara, and their international partners, is aimed at limiting the desertification of the Sahel zone. The building of this pan-African Great Green Wall (GGW) was approved by an international summit in Bonn. The GGW, as conceived by the 11 countries located along the southern border of the Sahara, and their international partners, is aimed at limiting the desertification of the Sahel zone. It will also be a catalyst for a multifaceted international economic and environmental program. The Sahel zone *sens lat*. is the transition between the Sahara in the north and the African savannas in the south, and includes parts of Burkina Faso, Chad, Djibouti, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Senegal and Sudan. The GGW initiative initially involved the planting of a 15 km-wide forest belt across the continent, with a band of vegetation as continuous as possible, but rerouted if necessary to skirt around obstacles such as streams, rocky areas and mountains – or to link inhabited areas. Its aim is to ensure the planting and integrated development of economically interesting drought-tolerant plant species, water retention ponds, agricultural production systems and other income-generating activities, as well as basic social infrastructures.

Box 9.4: Reforestation Using *Acacia albida*

Reforestation using *Acacia albida* (syn. *Faidherbia albida*), a fast-growing leguminous savanna tree, has been proposed to combat desertification in the Sahel. The tree provides valuable livestock fodder, hardwood, and enhances soil fertility. An initial 3-year (1976–1979) rural development project focussed on the establishment of *A.albida* plantations in southwest Chad. The final goal was an ecologically-oriented integrated land management program (Kirmse and Norton 1984). A community-based planting program of *Acacia albida* to enhance local livelihoods and for desertification control was carried out in southwest Chad.

13 Conclusions

Chad has demonstrated how the approach embodied in a participatory process was able to contribute to the formation and training of village committees who help organize their communities to fight bushfires and riverbank erosion and get involved in forest management. It helped communities create partnerships with technical service organizations who were able to provide land users with materials they needed for their development projects such as seedling production. It had positive outcomes for women's empowerment. These successes depended on a variety of different contextually appropriate communication tools ranging from video, to traditional musicians to theatre, to community meetings etc. A major achievement is the fact that when the results were shared with national coordinating bodies for the CCD, national committees of the PDLCD as well as NGOs who sponsor projects fighting desertification, those present were convinced to adopt and expand the experience as a useful tool for implementing the aims of the national action plans in combating desertification.

Some policies and regulations have already put in place and to have them fully implemented as part of a long-term national policy that will cover all the areas concerned is a continuing challenge. But there are measures that the government can take now:

- Educate people about the construction of Green belts
- Channel rivers manually to strategic locations
- Ensure that the areas severely affected by land degradation have enough water supply
- Ensure that the people of those areas have a proper diet and their diet is not affected by desertification-induced crop failure
- Channel a river to Lake Chad to act as major water source
- Plant more trees to enhance local transpiration

- Advise farmers and educate them about proper ways to grow crops including crop rotation
- Teach about the consequences of over grazing and risks of using primitive farming techniques
- Make better use of leguminous plants (intercropping) which will fix nitrogen making the soil more fertile and less subjected to desertification
- Promote the use of Solar Ovens and subsidize their purchase as a way to reduce pressure on fuel wood harvesting. Alternative fuel sources, such as gas and biogas, have been introduced in Chad and other countries, along with energy saving stoves and solar-powered cookers.

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Chapter 10
Desertification Control in Niger: The Medium Term Action Plan 2006–2011

Ibrahim Abdou

Synopsis The Chapter identifies some best practices and success stories and lessons learned that can inform the development and implementation of effective interventions to manage drought impacts and combat land degradation. This chapter is divided into three parts:

1. The environmental challenges and responses of Niger Republic
2. The medium term action plan 2006–2011 (MTAP)
3. Past and current measures to arrest and reverse desertification

Key Points

- The vast landlocked West African country of Niger faces an increasing demand upon its scarce water resources, the lack of which – when added to poor sanitation and hygiene – results in high levels of death and disease among its 17 million inhabitants. Niger is one of the countries that form the Sahel Region which has seen recurring drought, food insecurity, and increased desertification over the last 30 years, a result – at least partly – of global climate change and overuse of scant natural resources.
- Specific causes of desertification in the dry lands of Niger include land degradation resulting from drought, inherent low soil fertility/declining soil fertility, inadequate feed and fodder for livestock, depletion of surface and ground water resources, low forest cover, poor legislative framework, poor coordination of program activities and inadequate capacity for program planning, formulation and implementation. These specific issues relating to desertification and factors responsible for them are being tackled under the National Action Plan to combat desertification and the implementation of the MTAP.

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- Significant efforts have been made during the last 30 years in order to reduce the impacts of the environmental scourges and reverse the tendency to the deterioration of natural resources and areas. The efforts are increasing since 1984 following the national debate on the desertification control and particularly during the last 5 years with the effective engagement of the highest authorities.
- An outcome of the Environment and Desertification Control initiative was the Medium Term Action Plan and this, it is hoped, will guide Niger's effort to combat desertification. The purpose of the MTAP is to implement the orientations, strategies and programs of the SRP (strategy to reduce poverty) and the SRD (strategy for rural development) in relation to environment and desertification control.
- Rural population pressure is responsible for over exploitation of land in a bid for survival. The problem is exacerbated by climate variability driven by global climate change, in this case prolonged drought, desertification, higher temperatures and greater rainfall variability. The trend poses serious challenge and concern to the national government and communities directly affected. There is urgent need to tackle the situation or Niger will face irreversible loss of biodiversity and reduction of land fertility which will seriously affect agriculture, food security, the corresponding living standards and economic well being of the local communities. Soil desiccation and sparseness of vegetation cover are responsible for speedy removal of topsoil by wind action leading to dusty or hazy weather and widespread desertification.

Keywords MTAP • Poverty • Sand dune fixation • Cattle • Climate change • Resource use • Success stories • Lessons learned • Siltation of watersheds • Wildlife • Endangered species • Invasive plants • Drought • Biodiversity • Reserves

1 Introduction

Niger, a landlocked country located in west Africa (Fig. 10.1), resembles many other Sahelian countries affected by drought conditions. Erratic rains have greatly limited the chances of survival for both humans and animals in this marginal environment. Furthermore, years of civil disturbances have ruined an already precarious economy and have robbed it of many of the critical resources needed to control its environment. Recent data has confirmed Niger as being one of the poorest nations on earth with a per capita income of less than US 100 per annum.

Niger is one of the countries that form the Sahel Region which has seen recurring drought, food insecurity, and increased desertification over the last 30 years, a result – at least partly – of global climate change and overuse of scant natural resources. In recent times, food insecurity and drought reached abnormally high levels, prompting a response from the international community and an intensive food security operation undertaken by the International Federation of Red Cross and Red Crescent Societies.

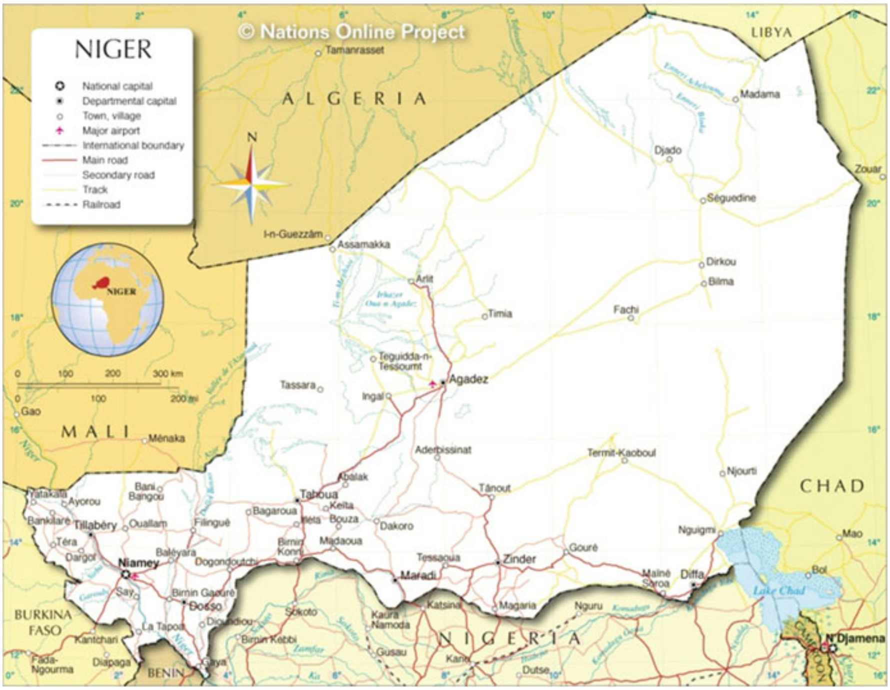

Fig. 10.1 Map of Niger Republic and it neighboring countries. The country is bordered to the north by Algeria and Libya, to the west by Mali and Burkina Faso, to the east by Chad and to the south by Benin and Nigeria

2 Environmental Challenges and Responses

2.1 Socio-economic Context

Niger's population was about 17.5 million in 2011 with about half of them under 18 years of age. The annual growth rate of 3.3 % is one of the highest in Africa. Rural industries provide a livelihood for the majority. The production from agriculture, cattle breeding, forest, fauna and fishing provides 41 % of the GDP and provide 44 % of the export income.

At the national level, the poverty profile indicates 63 % are classified as poor, among which 86 % are in the rural areas. Totally, 66 % live below the poverty line. Many of them subsist on less than a dollar a day following traditional farming and livestock rearing in this harsh and uncompromising climate. The health situation is characterized by a high prevalence of diseases such as malaria, tuberculosis and other respiratory infections. Regarding education, one child in two has access to primary education; one in ten to secondary and only one adult in five is fully literate. The gross percentage of children in full time education is about 35 %.

Fig. 10.2 Massifs of Air (Ing. foresters going to the steering committee meeting for Sustainable Co-management of the Natural Resources of the Air-Tenere Complex: Iferuan June 2012)

Niger is one of the poorest countries in the world. Its fragile economy is heavily based on agriculture and cattle breeding (75 % get their incomes from the land). The low speed of economic growth, inflation and external and internal imbalance, severely affect the standard of living of the populations. During recent years, Niger experienced a series of social and political crises which led, to a deterioration of public finance and the slowing down of production activities. Despite the difficult economic situation, the socio-political environment is relatively stable since the end of 1990s thanks to the adoption of democracy. The ongoing decentralization process is one of the major events of the present situation. Since the adoption of the first pilots in 2001, it symbolizes the hopes for change which the country really needs for its development. The creation of the 265 communes and the establishment of regional and local councils are the determining factors announcing a new era of governance.

2.2 *Physical Environment*

(a) **Relief:**
Niger covers an area of 1,267,000 square km (km^2) with 500,000 km^2 of desert lands (Tenere and Tall). It lies on continental sediments strongly leveled by erosion. Characterized by low altitudes (200–500 m), the relief is marked by very ancient mountainous massifs in the north- west (massifs of Air). Further in the south, going from west to east, the topography is shaped by the plateaus of Adar Doutchi Maggia, Damagaram, Damergou and Koutous and the vast sand plain of Manga (Fig. 10.2).

(b) **Climate:**
The climate is of the continental sahelian type characterized by two seasons: a rainy season from June to September and a dry season from October to May. The *harmattan*, a continental sandy wind from northeast mostly hot and dry blows during the dry season, whereas the monsoon, a south-west wind, both maritime and humid blows during the raining season. The temperature is permanently high except in the desert zones where the thermal variations are relatively significant. The highest temperatures are reached in May and the minimum in February.

(c) **Soils:**
The soils, mostly sandy, are characterized by a general deficiency in organic matter and phosphorus, a continuous decrease of fertility, a tendency to acidification, a low capacity of water retention and a high sensitivity to hydraulic and wind erosion. Furthermore, there is a trend to alkalinization and salinization around the hydro-agricultural areas and basins.

(d) **Vegetation:**
By virtue of its spatial extent the country encompasses various climatic regimes and physiographical units that give rise to a wide variety of ecological zones. These zones range from lush forest vegetation in the south to Guinea savanna in the middle belt region, Sudan savanna in the north and Sahelian vegetation in the extreme northern part of the country. Of these ecological zones, the Sudan and Sahelian regimes are most vulnerable to climatic and human pressures. The decreasing aridity pressure gradient from north to south established four large zones which are superimposed on the east–west oriented bands. The last two (sahelian zone and soudano-sahelian zone) are home to 80 % of the population.

1. The Saharan zones are characterized by a discontinuous shrub-steppe. Riparian vegetation forms thickets of *Acacia* spp. and palm trees (*Hyphaene thebaica*) along water flows and sewage areas. The steppe is dominated by *Acacia erhenbergiana* in Irhazer and Tadress areas.
2. The sahelo-saharan zones are dominated by pseudo-steppes. *Acacia raddiana*, *A. Senegal and Commiphora africa* are found on the sandy sub strata which covers the biggest part of the Nigerien sahel whereas *Acacia nilotica*, *Balanites aegyptiaca*, *Maerua crassifolia etc*. are more adapted to muddy soils.
3. In the sahelian zones, the vegetation takes the form of bushy savanna where the dominants are *Acacia albida*, *Acacia Senegal*, *Borassus aethiopium*, *Hyphaene thebaica*, *Combretum glutinosum* etc. These areas are agro-pastoral and are highly populated.
4. Finally, the soudano-sahelian zone which has forestry coverage of wooded savanna. In these areas plantings of the Family ***Combretaceae*** dominate but other species such as *Butyrospermum parkii*, *and Parkia biglobosa* are also present.

(e) **Fauna:**
Niger contains many biotopes of exceptional biodiversity represented by about 3,200 animal species (including invertebrates). It shelters the last specimen of west African giraffes and many species of mammals and birds of international importance through its network of protected sites in both desert and wetlands (National park of W, National natural reserve of Air and Tenere, Termit, Tadress, Gadabegi, Niger river parks etc.).

(f) **Watershed and wetlands:**
There are two broad hydrographical basins:

- Chad Lake basin;
- River Niger basin.

The country counts 1.45 Mha of wetlands of international importance. Many other, non classified, sites exist such as Tabalak (7,713 ha); Lassouri (32,740 ha), Dan Doutchi (29,081 ha), the Goulbi and Koroma. Despite being landlocked, Niger has a high potential of fish breeding. It is estimated that around 400,000 ha in the watersheds (River Niger, and its tributary Komadougou Yobe, Lake Chad), in 970 natural ponds and 69 artificial water reservoirs offer huge under-exploited opportunities. In this regard, the progressive return of the waters to Lake Chad gives hope for development of fishing activities.

3 Environmental Challenges

The vast landlocked West African country of Niger faces an increasing demand upon its scarce water resources, the lack of which – when added to poor sanitation and hygiene – results in high levels of death and disease among its 17 million inhabitants.

Niger is one of the countries that form the Sahel Region which has seen recurring drought, food insecurity, and increased desertification over the last 30 years, a result – at least partly – of global climate change and overuse of scant natural resources.

During the last few years, food insecurity and drought reached abnormally high levels, prompting a response from the international community and an intensive food security operation undertaken by the International Federation of Red Cross and Red Crescent Societies.

Climatic aridity, natural resources deterioration, low economic growth, population explosion and poverty combine, through their multiple links of cause and effect, to define the major environmental problems in Niger, and most particularly the issue of desertification. Better known now, these phenomena continue to create enormous damage to the natural resources and overall environments, making the productions and the living conditions of human communities uncertain and extremely precarious (Fig. 10.3).

The major challenges confronted by the national communities of those engaged in agriculture and pastoralism are as follows (See also Table 10.1).

Fig. 10.3 Niger is a Sahelian country faced with many problems of desertification including loss of precious topsoil that threaten food security

3.1 Soil Degradation

Every year, thousands hectares of arable soils are lost from croplands and rangelands by the erosion. In the regions of Agadez, Diffa, Zinder, Tillabery, Tahoua and Maradi wind erosion is the most important factor of environment degradation. The siltation of croplands, water basins, rivers and infrastructures (road and water points) by moving sands is one of the most devastating forms of desertification. In the regions of Tahoua, Tillabery, Niamey, Dosso, Maradi and Zinder, water causes enormous erosion which takes away the fertile topsoil, creates ravines and silts up the watersheds, including reservoirs. Finally, the sandy cropland soils of the departments of Maradi and Zinder, zones of cereal crops culture, are drastically losing their fertility due to depleted soil organic matter levels, loss of topsoil and shortened rotations – all due a high demographic pressure (Figs. 10.4 and 10.5).

In the context of advanced and generalized degradation of soils, the natural resource capital is characterized by low productivity and accessibility. Despite the exploitation of more marginal land, the increasing of basic cereal productions (2.5 % by year) is still much less than that of the population (3.1 %). It is the same for fodder productions and planting of shelterbelts. Under the demographic pressure, the extension of cropland reduces significantly the sylvo-pastoral space which is in constant deterioration. This deterioration is translated by the decrease and even the complete extinction of species (herbaceous as well as ligneous), thus dangerously compromising the development of the secular activity of cattle breeding.

3.2 Regression of Forests and Vegetal Diversity

Habitat of fauna and source of energy, food and environment stability, the forests and protected sites are nevertheless very threatened by recurrent droughts and in particular soil clearing for agriculture, abusive exploitation of fire wood and non ligneous forestry products, bush fire etc.

Table 10.1 Issues relating to desertification in the drylands of Niger

The issues	Causes
Drought	Climatic variations
	Low soil water holding capacity
Inherent low soil fertility/declining soil fertility	Low soil organic matter levels of the drylands
	Cultivation of marginal lands
	Population pressure in reduced/eliminated fallow period
	Land tenure problems
Inadequate feed and fodder for livestock	Livestock population in excess of the carrying capacity of the rangelands
	Increasing migration of livestock from neighboring countries Chad, Nigeria and Burkina Farso
	Encroachment of crop cultivation into designated livestock routes and grazing reserves
Depletion of water resources (surface and groundwater)	Damming of rivers, thus depriving downstream users of access to water
	Increasing human and livestock population
	Increasing demand caused by increasing urbanization and industrialization
Low forest cover	Excessive wood extraction for fuel construction (lumber)
	Bush burning
	Uncontrolled land clearing for agricultural purposes
Legislative framework	Low level of education and public awareness
	Conflicting policies and regulations
	Poor enforcement mechanism
Inadequate capacity	Uncoordinated research efforts on problems relating to drought and desertification
	Obsolete research and meteorological equipment
	Low and erratic funding for desertification control projects
Coordination of activities	Sectoral approach to project planning formulation and implementation
	Insufficient involvement of all stakeholders, particularly resource-users, in project planning, formulation and implementation

About 2,500 km^2, are being lost each year in Niger through desertification. This is equivalent to the area of Luxembourg. Studies carried out in the 1980 estimated the natural forestry potential at 16 Mha with a very low productivity of between 0.1 and 1.5 m^3/ha/year. The forestry structures exploited for wood-energy (about 4 Mha) provide around 90 % of the needs, that is to say three million tons per year. The "wood-energy assessment" established in the late 1990s indicated that some regions of the country are already in deficit. The problem of wood supply is particularly

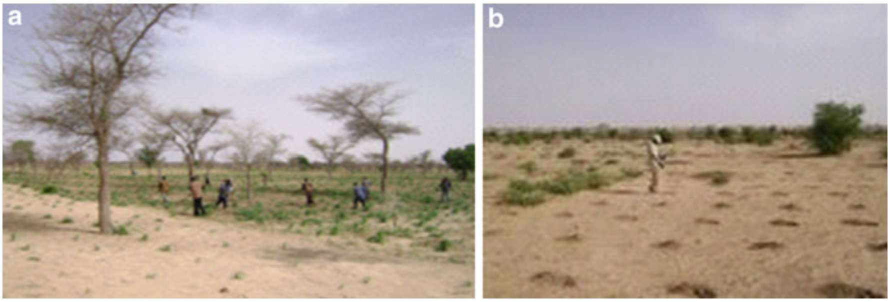

Fig. 10.4 (**a**) and (**b**) Pressure on marginal lands for conversion to millet farms leads to rapid land degradation

Fig. 10.5 Water erosion in a millet farm

acute in the regions of Tahoua, Maradi, Tillabery and Zinder. The local office of the Department of the Environment in Zinder, noted that firewood destined for Zinder town is collected up to 200 km away.

Besides the problem of wood-energy due to the reduction of biological diversity, the impact of the vegetal coverage degradation on communities' life touches other important dimensions. In fact: 210 vegetal species directly contribute to human feeding, particularly during food shortage and famine; 235 species are consumed by the cattle; 270 are used in traditional medicines; 127 species in the handicraft and habitat maintenance etc.

3.3 Sand Encroachment and Siltation of Watersheds

In their inexorable movement, the sands threaten to bury surface water like rivers (Niger, the Komadougou and the Korama); the roads and other development infrastructures. The sand dunes bury market gardens in the regions of Zinder and Diffa. The lakes and ponds are also under threat. Finally, in the north-sahelian band of the country, sand movement threatens croplands used for cereals by compromising the seedlings and 'sterilizing' the croplands and pastureland under a layer of pure sand because of the degradation of vegetal coverage.

3.4 Reduction of Animal Biodiversity

Many fauna species particularly the sahelo-saharan antelopes are under threat of extinction (Addax, *Gazella dama* for example). Some species such as the *Oryx spp*. are locally extinct. The park of W, created since 1954 is now facing the problems of degradation and uncontrolled exploitation (poaching, illegal *use of pasture*, *wood cutting*, *bush fire*, *encroachment by croplands*). Air-Ténéré National Natural Reserve (RNNAT) one of the largest World Heritage reserves (77,360 km^2) was since 1992 put by UNESCO in the list of endangered world heritage sites. Little attention is given to the other reserves (Gadabeji, Tadress etc.) and the zones adjacent to the protected sites. These reserves are also threatened by irreversible degradation. There is a great concern about the proliferation of certain undesirable species such as water hyacinth (*Eichhornia crassipes*), *Typha australis*, *Sida cordifolia* both within the reserves and elsewhere.

4 The Responses to Environmental Degradation

Actions were taken by Niger and its partners in response to the various challenges mentioned. Besides the political and institutional reforms courageously executed, many field operations are undertaken. The achievements (below) give hope.

4.1 At the Political and Institutional Level

At the political level, the priority given to the improvement of the ecological environment is clearly translated in the Strategy for Reducing Poverty (SRP) and more explicitly, in the framework of the Strategy of Rural Development (SRD). This strategy mainly focuses on the protection of the natural resources and sustainable management. Finally, the government's recent declaration underlined this priority and particularly the urgent need to implement the adopted orientations and objectives. Measures are now included in the new (2012) program of the government. In fact The new program is now called Program of Economic and Social Development (PDES 2012–2015 in French). Those strategies mainly focus on the protection of the natural resources and sustainable management. Finally, the government's recent declaration underlined this priority and particularly the urgent need to translate into fact the adopted orientations and objectives in the Strategy for Sustainable Development and Inclusive progress 2035 (SDDCI in French).

At the institutional level, many reforms have been made and others are underway in order to strengthen the mobilization of the population and improve the efficiency of the public services and civil society organizations relating to environment. Among these efforts, the adaptation of land laws and the support to the emergence of local and private initiatives should be particularly underlined That is why the government in 2012 adopted a policy called i.3N (les Nigeriens Nourrissent les Nigeriens meaning 3N initiative: The Nigeriens feed Nigeriens) and created the higher commission to 3N initiative. Under this initiative which is the third axis of the PDES and SDDCI the policy of combating desertification is involved. The following are part of this program:

- Niger: Management and conservation of Badaguichiri's Basin (2010–2014)
- Niger: Oasis micro-basin sand invasion control in the Goure and Maine-Soroa Provinces (PLECO)
- Niger: Integrated Ecosystem Management (IEM) of the transboundry areas between Niger and Nigeria (see Obi 2012)
- Niger: Pilot Project of Climate Residences' (PPCR)
- Niger: Community Actions Projects (CAP II)
- Niger: Promoting Local Initiative Development Project
- Niger: Lake Chad Basin Development Project (2010–2014)
- Niger: Green wall Initiative (2010–2015)
- Niger: Sustainable Co-management of the Natural Resources of the Air-Tenere Complex.

4.2 At the Operational Level

Significant efforts have been made during the last 30 years in order to reduce the impacts of the environmental scourges and reverse the tendency to the deterioration of natural resources. The efforts are increasing since 1984 following the national debate on the desertification control and particularly during the first 5 years of the new century with the effective engagement of the highest authorities the under 3N program initiative

Many projects have been carried out with the support of friendly countries and international institutions in various areas such as:

- Soil recuperation;
- Reforestation;

Fig. 10.6 Mechanical restoration of degraded land by women at Iferuan community, June 2012

Fig. 10.7 Moving sand dune (Maine-Soroa) Sep. 2012 (Compare Fig. 10.11 to see the value of the sand fixation work)

– Natural forest structuring;
– Fight against siltation;
– Protection of the fauna;
– Surface water collection etc.

These projects allowed getting significant experiences that should be deployed in the rehabilitation of the environment at short, medium and long terms (Figs. 10.6 and 10.7).

4.3 The Sectorial Consultation

The sectorial consultation on the Environment and Desertification Control initiative arose from the firm determination of the government of the Niger to engage in a resolute fight against the environment scourges. It was organized in order to:

– Share with the development partners the national vision of the environment problems and appreciate the relevance of the strategic and operational framework adopted to face them;
– Motivate partners' adherence to the present Medium Term Action Plan (MTAP) as a translation of this shared vision;
– Finally, improve partners' engagement to support the Niger in the implementation of the identified priority actions.

5 Medium Term Action Plan

An outcome of the Environment and Desertification Control initiative was the Medium Term Action Plan and this, it is hoped, will guide Niger's effort to combat desertification.

5.1 Purpose and Principles

5.1.1 Purpose

The purpose of the MTAP is to implement the orientations, strategies and programs of the SRP (strategy to reduce poverty) and the SRD (strategy for rural development) in relation to environment and desertification control. In this regard, it:

– Specified the relevant sectorial sub-programs and priority actions to be carried out during the 2006–2011 period;
– Contributed to a stronger mobilization of the country's partners in order to support the public and private sector actors, the civil society, the territorial communities and the local communities in their efforts of a sustainable management of the natural resources.

5.1.2 Principles

Conceived in the programmatic mould of the SRD, which it is now one of its components, the MTAP adopts the holistic approach that characterizes the two reference frameworks. It aims at combating poverty from an environmental point of view and takes into account the social, economic and ecological dimensions of development. It focuses on the capacity building of the local land users and managers of the natural resources. In this context, its implementation will favor the principle of solidarity, the promotion of local initiatives and equity.

The concept of the MTAP derives from an integrated exploitation of the strategies and the actions plans elaborated in a participative way within the framework of the previous planning processes. Among the considered strategies and action plans, are in particular (i) the *National Strategy and Action Plan for Biological Diversity* (SNDB) (ii) *National Action Plan for Desertification Control and Natural Resources Management*. Finally, the MTAP is designated as the instrument of a long term engagement of the various national environment actors and partners of the Niger, in the respect of the regional integration and the international engagements options. The identification of the objectives and the harmonization of the results and priority actions per components are carried out on the basis of the corresponding program of the SRD.

5.2 The Sub-programs of the MTAP

The MTAP is structured around the following seven sub-programs:

- Support to local governing of natural resources
- Soil restoration and reforestation
- Environment conservation
- Silvo-pastoral development
- Environmental crises prevention and management
- Strengthening Sections and professionals organizations
- Capacity building of the public institutional mechanism

5.2.1 National Action Plan for Desertification Control and Natural Resources Management

The set objectives of this National Action Program cannot be achieved unless the implementation of the proposed actions is properly monitored and periodically evaluated.

For this purpose, the following strategies should be adopted to ensure proper coordination and implementation:

- Strengthening of the National Coordinating Committee on Desertification Control (NCCDC).
- and review periodically the implementation of the National Action Program.
- Strengthening of the capacity of the NCCDC Focal Point and Secretariat in the Federal Ministry of Environment.

- Development of Benchmarks for assessing progress of Program Implementation.
- Submission of Quarterly Progress Reports on the implementation of programs to the National Focal Point.

Using simple techniques such as planting trees and preserving natural vegetation, teams of workers have already rehabilitated three million hectares of severely degraded land, according to the Nigerien government. Some notable results have been recorded, but their impact could have been more meaningful had the approach been more global. To date according to various reports of the Ministry Environment:

– the production of 80,000,000 saplings which would correspond to an average reforestation of 8,000 ha per year
– The development of about 480,000 ha of forests
– the restoration of 107,000 ha of degraded lands
– the realization of 22,000 km of firebreaks

Surveying in parts of southern Niger has found between 10 and 20 times more trees in 2005 than 30 years earlier.

In 2008, the government launched the second phase of the campaign, targeting 1,530 ha of dunes, which threaten to bury valleys and roads. The plan will give work to more than 60,000 people in the cash-strapped country. While a total of 750 ha of sand dunes had already been improved, the government plans to restore a further 15,000 ha of degraded lands and 1,500 ha of oasis-based watering schemes, for a total of about US $2.8 million each year.

UNDP has been active in two projects:

- Niger: Oasis micro-basin sand invasion control in the Goure and Maine-Soroa Provinces (PLECO) under the Strategic Investment Program for SLM in sub-Saharan Africa (SIP).
- Niger: Sustainable Co-management of the Natural Resources of the Air-Tenere Complex.

5.3 Possible Solutions to Niger's De-forestation and Fuelwood Problem

5.3.1 Farmer Managed Natural Regeneration

A program for making wood production more efficient was launched in Niger in the1980s. It involves putting the villagers at the heart of the strategy and making them the true custodians of the rural landscape. They manage their forest capital and in return they recuperate an income generated by their activity. This policy preserves biological diversity, provides jobs and revenue to the villagers (see below) and boosts the states' tax receipts.

Fig. 10.8 Bush burning for agricultural purpose (create more arable land)

Beginning in the 1980s, a new method of reforestation, Farmer Managed Natural Regeneration (FMNR), became an increasingly popular solution to the rapid deforestation problem.

During the 1950s and 1960s, rapid deforestation of land in Niger for agricultural purposes (Figs. 10.8 and 10.9) resulted in severe desertification.

Conventional tree planting to combat desertification had only limited success. Beginning in the 1980s, a new method of reforestation, FMNR, became an increasingly popular solution to the problem. FMNR is based on the regeneration of native trees and shrubs from mature root systems of previously cleared desert shrubs and trees. Regeneration techniques are used in agricultural cropland and to manage trees as part of a farm enterprise. FMNR in the savannas of southern Niger adapts centuries-old methods of woodland management to produce continuous harvests of trees for fuel, building materials, and food and fodder without the need for frequent, costly replanting. Trees are trimmed and pruned to maximize harvests while promoting optimal growing conditions (such as access to water and sunlight).

Government decentralization policies supporting land tenure and tree growth reforms. Not for profit organizations, donor governments, and international aid agencies are encouraged and these have assisted farmers in adopting low-cost techniques for managing the natural regeneration of trees and shrubs.

The benefits of the project are as follows:

- Improved food security as at least 250,000 ha of degraded land reclaimed for crop production;

Fig. 10.9 Forest Rangers assessing the number of trees cut down to make way for cropping

- Expanded cultivation of cereals and vegetables, with harvests doubling in some areas;
- Many rural producers have doubled or tripled their incomes through the sale of wood, seed pods, and edible leaves;
- Improved stocks of fuel wood and fodder;
- Average time spent by women collecting firewood has fallen from 2.5 hours to half an hour;
- An increase of 10–20-fold in tree and shrub cover on about five million hectares of land, with approximately 200 million trees protected and managed;
- Soil fertility improved as higher tree densities act as windbreaks to counter erosion, provide enriching mulch and fix nitrogen in root systems;
- Increased population of wild fauna, including hares, wild guinea fowls, squirrels and jackals;
- New food export markets created, primarily to Nigeria;
- Creation of specialized local markets in buying, rehabilitating, and reselling degraded lands, with land values rising by 75–140 % in some areas.

To succeed, development policy must take into account its principal potential users, in this case, the local villagers from the forest areas. Starting in 1981, the state initiated and tested a new control policy for the exploitation of wood while managing the protected forest of Guesselbodi, among others. Other forest planning developments have been implemented, such as in the forest region of Gorou Bassounga and Faira, to name but two. Furthermore, the wood consumption

Fig. 10.10 Members of the steering committee of Sustainable Co-management of the Natural Resources of the Air-Tenere Complex (C0GERAT in French) visiting a private site of outreach bridging (May 2012)

of households is managed in a way that will not cause shortages in the future, particularly in towns. Alternatives to wood such as petrol or gas are being promoted. Although these are non-renewable energy sources, they do present less immediate damage to the environment.

The production and distribution of wood, the commercialization of which takes place in rural markets is also important. Set up by private operators, these markets are places where wood and charcoal is sold and are managed by local producers, away from large cities. Policy not only ensures that the wood comes from controlled production, which is more competitive than traditional production, but also more importantly, it insists on the rational and controlled utilization of wood resources.. The rural firewood markets are held close to the plantation sites and it is the responsibility of the wood trader-transporters to deliver the wood to urban centers. Satisfying the energy needs of the Niger population, without destroying their production source, is their major concern and is part of the program to combat desertification and land degradation.

3 –Lessons learned from MTAP implementation (Past and current measures to arrest and reverse desertification).

Some good practices have been developed during the last years in terms of sustainable development of natural resources and environment conservation. These contributed to secure the agro pastoral systems and adaptation to climate change. These good practices include: reforestation, natural regeneration (vegetation) improvement ; farm clearing system improvement ; wind break, life fences, bush burning and bush fire control, sand dune fixation, gully erosion control, forest management, urban and peri urban forestry improvement (Figs. 10.10, 10.11, and 10.12).

Fig. 10.11 Sand dune fixation at Maine Soroa Sep. 2012

Fig. 10.12 Women harvesting *Cassia tora* leaf (it is delicious food). This species has been reintroduced in 2008 in land restored within the UNEP IEMP project (Dogueraoua pilot site of IEMP October 2010)

6 Conclusions

Drought and desertification continue to threaten the livelihoods of millions of people in Niger, increasingly making them unable to edge out of poverty. This trend is set to worsen with the onset of climate change, to which many regions in Niger are most vulnerable.

Mitigation measures and management options include both long term measures and short and medium term measures:

Long Term Measures include:

Pre-disaster planning to control drought: This includes integrated river basin development, development and implementation of a Strategic Planning Framework for the protection and sustainable management of natural resources and integrating them into National Development Plans (see MTAP). This is a strategy designed for intensive and multipurpose development of surface and ground water resources. Most important under this heading is definition of criteria for risk identification, risk prevention, mitigation, preparedness, relief plans, recovery and rehabilitation and comprehensive financial planning (which includes identifying funding sources) for the vulnerable population.

Agro-climatological research and proper land-use planning: Technical solutions include desalination, and watershed management. Large scale desalination maybe impractical because of the distance to the sea but re-use of irrigation drainage and brackish ground and surface water may be feasible. Watershed management is most suitable and this can be achieved through proper erosion control, water harvesting, water absorption capabilities and regulation of river flow through the use of dams and barrages. Use of large scale reforestation activity (green dam) on arid land planted to protect arid areas from sand encroachment and deforestation. Use of shelterbelts (row of trees) along roads and suburbs using drip irrigation with high drought resistant trees such as *Eucalyptus*, *Casuarina*, *Acacia*, cypress and gum-arabic trees. Increased fodder and forage production advocated with a view to increasing family incomes thereby reducing pressure on nearby rangelands. Mechanical stabilization of dunes prior to biological fixation with vegetation. Reforestation and afforestation schemes with shelterbelts and tree planting for ameliorating local climate conditions and check desert encroachment and wind erosion and also regulate sand dunes fixation.

Short Term Measures: Short term measure to control drought and desertification are usually taken during or after the occurrence of the events usually, short term reactions to crisis situation.

Provisions of Drought Relief Schemes: They include:

- Food distribution or relief materials to victims with assistance of international relief agencies such as Red Cross, UNICEF, and UNEP etc.
- Emergency sinking of wells and boreholes, and construction of small irrigation works. Rehabilitation and Recovery programs and their integration into National Development Plans including afforestation and reforestation.

- Establishment of community plant nurseries, woodlots, wind breaks and botanical gardens for conservation of threatened fauna species.
- Ecological fund administration should make adequate funding provision channeled towards prevention, mitigation and adaptation strategies for gender specific policies on emergency response and disaster preparedness.

Non Technical Measures: This will include water rationing, water use restrictions, water use education, and use of pricing mechanism or metering though this method may be difficult in view of the level of poverty in the greater populace and the possibility of jeopardizing health hygiene standards. Development of national drought forecasting and early warning system including indicator maps for effective adoption of appropriate mitigation measures and pro-active strategic decision making. A comprehensive drought and desertification containment plan must integrate both long-term and short-term measures which must include elements of pre-disaster planning as well as crisis management when disaster occurs. The local communities need to be involved because they have fore knowledge of the events as years evolved.

Land users make management decisions about inputs, operation and maintenance of farming systems that involve crops, livestock, marketing and animal health and about improvements to be made in the farming system as a whole. To improve their abilities to make these decisions, land users should be involved in the whole process of land management. In this way it is more likely that they understand why certain measures, introduced by outsiders, take place and why certain changes are to be made in farming and livestock management systems. On the other hand policy makers, administrators, project implementers and other actors, will better understand why land users take certain decisions and why they prefer certain traditional practices.

The role of land users in the process of combating desertification and arresting or reversing land degradation is gradually being appreciated and is being accepted as a vital component in land management. To involve land users in plans to implement sustainable land management leads to an understanding of the meaning land users attach to world-view. To accomplish this there needs to be a communicative process in which there is exchange of views and discussion. Not knowing land users's priorities and not including their agenda in policy formulation mean that professionals are likely to address the wrong problems. Land user involvement is seen as a necessary ingredient to enhance the effectiveness of land management. Land users should be involved in planning, implementation, monitoring and evaluation of land degradation related issues.

The following are the key conclusions:

- Desertification and drought are at the heart of development challenges in Niger and merit urgent attention in policies and actions at national regional and global level.

- Combating desertification in Niger has tremendous benefits in enhancing progress towards meeting Millennium Development Goals (MDGs) particularly in terms of poverty reduction, attaining food security, combating diseases and ensuring environmental sustainability. Otherwise current trends in land degradation and high level of vulnerability of the region to the impacts of both drought and desertification will be major impediments to the attainment of the MDGs as well as ensuring security and social stability at all levels in the region.
- Niger has responded and made some demonstrated progress towards tackling drought and desertification. The UNCCD has been central and provides vital opportunities for tackling drought and desertification in Niger. With support from international partners, Niger is taking some concrete action at various levels to tackle desertification as well as to mitigate the impacts of drought
- Implementation of these plans has commenced and urgently needs to be scaled up with a special emphasis on achieving implementation and impact at local level. In this context mechanisms are needed for providing technical and long-term financial support for combating drought and desertification especially to decentralised local government and communities.
- Work has commenced, but major effort is needed to strengthen the establishment of systems for drought and desertification monitoring, early warning and drought risk management. In this connection concrete data about current rates and extent of desertification needs to collected and disseminated to inform policy development and implementation.
- Niger continues to face a number of challenges and constraints that constitute major impediments and hamper progress in addressing drought and desertification and attaining sustainable development. Notable are the high levels of poverty, weak institutional capacities, challenges in resource mobilization, weak information base, and inadequate access to affordable appropriate technology. These impediments merit urgent attention if progress is to be accelerated.
- The main priority approaches and actions proposed to accelerate progress, recognize the need to address the root causes of desertification, respond to the main challenges, tackle constraints, and upscale implementation of existing programs and plans for SLM building on the success stories.
- In order to succeed and achieve significant progress in combating desertification and mitigating impacts of drought, there is need for enhanced political will and commitment at all levels to address these problems as integral priority element within MDG and poverty reduction based programs and strategies.
- Through a mix of soil and water conservation techniques, combined with better tree and pasture management, simple and low cost farmer led innovations and technologies can help achieve sustainable farming systems needed to combat land degradation. Building on and reinforcing these innovations and technologies with outside expertise and resources support can foster achievement of greater results
- One solution to desertification is for farmers to stabilize their environment themselves by inter-cropping edible perennials in their fields. Perennials act as anchors that stabilize the soil against wind and water erosion and also improve

fertility. This protects the natural green belt because farmers respect perennials if they cultivate them making it less likely that they cut them down. Where farmers intercrop annuals with perennials, their land will produce more food both from the perennials and from increased yields from annuals lessening the pressure to move into the natural green belt. Farmers can re-vegetate by their own initiative and they then retain their dignity because Westerners are not re-vegetating their land for them. Of course donors can provide support to farmers and give advice about which species they should use.

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Part IV
Desertification in Selected Asian Countries

The Asian continent is vast and conditions vary from the world's highest mountains to extensive deserts, and huge populations of people and their livestock. These conditions give rise to different problems and to different approaches to solving them.

The examples chosen here include Mongolia, a north Asian semi-arid land, Uzbekistan, a major Central Asian country, and Pakistan in south-west Asia. All three countries have a high dependence on extensive rangelands and the livestock industry they support. Each country has adopted strategies and programs to combat desertification and these are outlined. We also include three Case Studies – The Philippines, Myanmar and the island of Sri Lanka – to indicate the scope and challenges of combating land degradation and drought impacts.

Chapter 11
Mongolia: Country Features, the Main Causes of Desertification and Remediation Efforts

O. Dorj, M. Enkhbold, S. Lkhamyanjin, Kh. Mijiddorj, A. Nosmoo, M. Puntsagnamil, and U. Sainjargal

Synopsis Mongolia's efforts to combat desertification are outlined. There is a new action plan and a strategy is in place. Legislative reform has sought to make new provisions for securing land users rights and securing tenure over grazing lands. Community-based Grasslands Management in Mongolia's Gobi has proven successful in raising household incomes. Examples are given of successful projects.

Key Points

- Agriculture is one of the key sectors of Mongolian economy. Nearly 80 % of Mongolia's territory is used for agriculture. Nearly half of the working population is engaged in agriculture, and many changes in agriculture sector have been taking place recently. The agricultural sector consists of two main subsector, these are crop production and livestock production.
- Vast pasture resources, the harsh climate and low population densities have favored the evolution of extensive livestock/pastoral livestock production in Mongolia. New livestock breeds of cattle, sheep and goats were developed for the extensive livestock production system. The newly-emerged intensive livestock subsector is characterized by using foreign breeds which have a higher productivity.
- Main causes of desertification are anthropogenic impacts, which accelerate the process of land degradation created by natural impacts such as global warming, drought and climate change. These factors are interrelated; sometimes they are affecting each other positively, and other times negatively. Human activities as a

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factor of desertification occur in the frame of natural dryness, causing negative impacts. Within these anthropogenic factors, animal husbandry has the strongest influence throughout the years by its exploitation of pasturelands that covers 80 % of the total territory.

- There has been a shift from sheep keeping to goat keeping among herders who are trying to respond to the growing international demand for cashmere wool. Goats, however, are much more harmful to the environment than sheep because they disturb the pasture's regenerative capacities by feeding on roots and flowers. Consequently, the shift to goat keeping is putting increasing pressure on the pasturelands in Mongolia, threatening to accelerate pasture degradation and processes of desertification. Over the past few years, the number of goats has increased significantly by ten million. Currently, goats make up 47 % of the total number of livestock in Mongolia.

Keywords Gobi • Cashmere • Land use rights • Dust storms • Infrastructure protection • Forests • Water supply • Biodiversity • Climate change • Population growth • Market economy • China • Republic of Korea • Russia • Legislation • Strategic plan • Dzud • Constraints • Dinosaurs

1 Country Background

1.1 Geographic Location

Mongolia is located in Central Asia bordered by Russia to the north and China to the east, west and south (Fig. 11.1). It has 1,566 million square kilometer (km^2) in area with maximum extent west–east of approximately 2,200 km and north–south 1,250 km, but sparsely populated with an average density of 1.5 persons/km^2. The 18th largest country in the world, 5th in Asia.

Elevation in Mongolia ranges between 560 meters above sea level (m asl) and 4,374 m asl, with an average altitude of 1,580 m asl.

1.2 Landscape

There are mountains in the north and west. Nearly 10 % of the land is forested, mostly in the north. The Central Region is steppe or grassland. The southern part of Mongolia is Gobi or semi-desert. Most of rivers and lakes are located in the northern part of the country (Fig. 11.2). Nearly 90 % can be used for agricultural or pastoral pursuits, 9.6 % is forest and 0.9 % is covered by water. Less than 1 % has no effective use.

Fig. 11.1 Geographic location of Mongolia and the location of population centers, It is the 18th largest country in the world, 5th largest in Asia

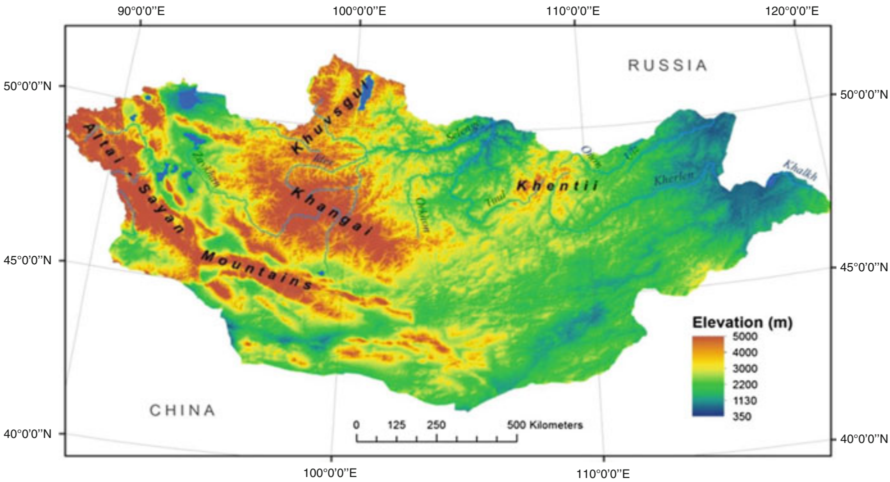

Fig. 11.2 The southern regions of Mongolia are desert whilst in the north and north-west there are uplands with forest cover

1.3 Climate

Mongolia has an extreme continental climate, very cold in winter and warm in summer. The average temperature ranges from +35 °C in summer to −40 °C in winter. There are over 250 sunny days a year. Some western and northern mountains areas in the country receive 450–1,000 mm precipitation. Precipitation in the northern and central areas is approximately 300 mm and the eastern southern areas receive less than 200 mm precipitation. The short growing seasons, low precipitation and high evapo-transpiration are the overriding constraints of Mongolian agriculture.

1.4 Population

The population of Mongolia is just over 2.7 million. Mongolia is one of the least densely populated countries of the world. The capital and largest city is Ulaanbaatar, has a population of 700,000. The annual population growth is about 2 %. Nearly 95 % of the population are Mongolians and 5 % of the population are Kazakhs and others. The main religion is Buddhism. Since the democratic changes of 1990 in Mongolia, religion has been practiced widely. Now people have freedom of belief and many monasteries have been reopened. The official national language is Mongolian.

2 Agriculture in Mongolia

Agriculture is one of the key sectors of Mongolian economy. Nearly 80 % of Mongolia's territory is used for agriculture. Nearly half of the working population is engaged in agriculture, and many changes in agriculture sector have been taking place recently. The agricultural sector consists of two main subsector, these are crop production and livestock production.

2.1 Crop Production

The total arable land is 1.3 million hectares (Mha), half of them was sown to crops and bare fallow. Crops are mainly wheat, barley, oats, potatoes, and vegetables. The main types of vegetables grown are cabbage, carrots, onions, and turnips. Mongolia is still importing flour, sugar, fruits, some vegetables, and sunflower and soybean oil from abroad.

2.2 Livestock Production

Livestock breeding is very important and contributes about 70 % of the gross agricultural output. The livestock sector accounts for 20 % of economic output in the Mongolian economy and translates directly into a source of employment and livelihood for at least 40 % of the population. The national livestock herd was estimated at almost 32 million heads at the end of 2000. But dropped dramatically as a result of the severe dzuds. However by 2007 the livestock inventory had risen sharply. The 2007 annual livestock census reported an increase of 15 % of livestock from 34.8 to 40.3 million livestock, with the number of goats, sheep and cattle increasing by 18, 15 and 14 % respectively Livestock farmers and

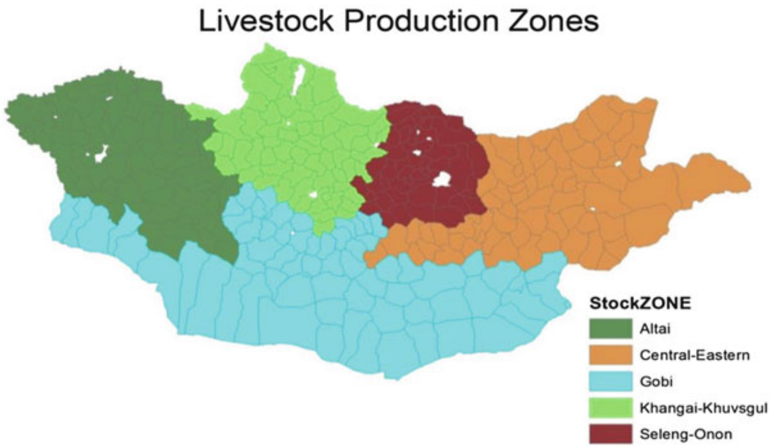

Fig. 11.3 Livestock production zones based on description by Suttie (2005)

herders produce meat, milk, dairy products, wool, cashmere and leather. Vast pasture resources, the harsh climate and low population densities have favored the evolution of extensive livestock/pastoral livestock production in Mongolia (Fig. 11.3). New livestock breeds of cattle, sheep and goats were developed for the extensive livestock production system. The intensive livestock subsector is characterized by using foreign breeds which have a higher productivity. The subsectors raise or produce mainly dairy cattle, sheep, pig and poultry.

3 Mongolian Gobi

The Mongolian Gobi is a vast zone of deserts and desert steppe covering almost 30 % of the Mongolian territory and also of the Northeastern China. The gobi is often imagined as a lifeless desert, but in reality it is a land of steppes that serve as a viable habitat to humans and wildlife alike. Many camel breeders inhabit this zone, which is also rich in wildlife and vegetation.

The Mongolians say that there are 33 different Gobi, from which sandy deserts occupies a mere 3 % of the total area. The gobi's climate is extreme, with +40 °C in summer to −40 °C in winter. It has very little precipitation. The Mongolian Government established the Great Gobi Strictly Protected Area in 1975. In 1991 the United Nations designated the Great Gobi as the fourth largest biosphere reserve in the world. The protected area is divided into two ecologically distinct parts, the southern Altai Gobi and the Dzungarian Gobi. The Gobi was originally an ancient island sea basin. Later it became home to many species of dinosaurs, and today has reservoirs of fossilized dinosaur bones and eggs. A complete dinosaur skeleton and eggs are exhibited at the Museum of Natural History.

4 Desertification in Mongolia

Mongolia's land area is 1,564,416 ha, with 8.3 % covered by forest, 80 % pastureland, and 1 % for cultivated farmland. About 90 % of the total area of the country has the potential for desertification and 41.3 % is considered as desert and desert steppe zone. Main causes of desertification are anthropogenic impacts, which accelerate the process of land degradation created by natural impacts such as global warming, drought and climate change. These factors are interrelated; sometimes they are affecting each other positively, and other times negatively. Human activities as a factor of desertification occur in the frame of natural dryness, causing negative impacts. Within these anthropogenic factors, animal husbandry has the strongest influence throughout the years by its exploitation of pasturelands that covers 80 % of the total territory. There has been a shift from sheep keeping to goat keeping among herders who are trying to respond to the growing international demand for cashmere fiber. Goats, however, are much more harmful to the environment than sheep because they disturb the pasture's regenerative capacities by feeding on roots and flowers. Consequently, the shift to goat keeping is putting increasing pressure on the pasturelands in Mongolia, threatening to accelerate pasture degradation and processes of desertification. Over the decade ending 2010, the number of goats has increased significantly by ten million. In 2010 goats made up 47 % of the total number of livestock in Mongolia.

Therefore, effective pastureland management is the best solution in combating desertification. Pasturelands constitute one of the key resources for the livestock based economy in Mongolia. According to the 2005 Land Inventory Report, 116 million ha or 73.9 % of the total land surface of Mongolia can be considered as pastureland. Being one of the key resources in the Mongolian economy, therefore, effective pastureland management is the best solution in combating desertification. Improved pastureland management has the potential to improve both rangeland health and rural livelihoods (Bedunah and Schmidt 2004; Nixson and Walters 2006)

Mongolia is divided into six natural zones: tundra; high mountain; forest steppe; typical steppe; desert steppe; and desert (see Fig. 11.4). The pasture productivity, dominant species and type, length of growing season and phenology are different for each of these natural zones. The pasture productivity, for instance, ranges between 150 and 1,500 kg/ha increasing from the deserts in the south to the forests and forest steppes in the north.

4.1 Factors Influencing Pasture Resources

Historic changes in pasture resources have been examined (Saizen et al. 2010; Shestakovich 2010) with a view to understanding how these changes can be related to shifts in climate and to socio-economic developments.

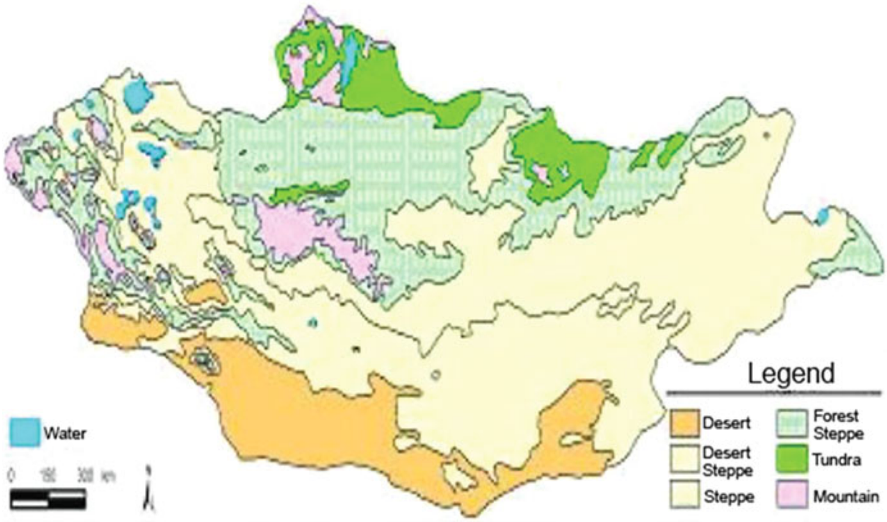

Fig. 11.4 Natural zones of Mongolia showing principal vegetation types

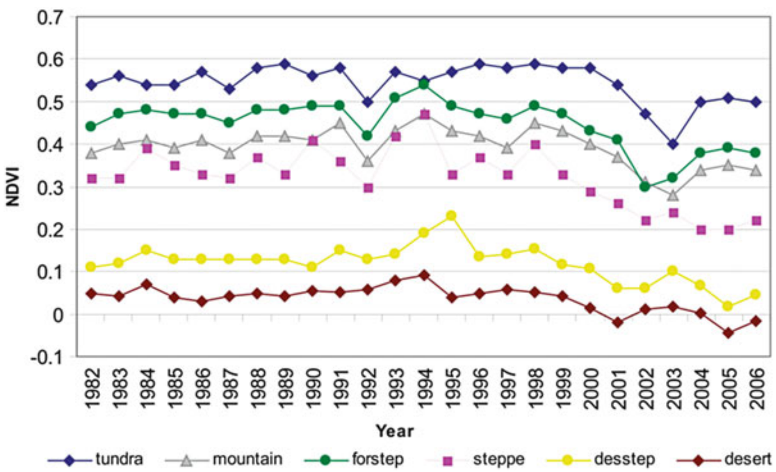

Fig. 11.5 Trends in NDVI in five different zones of Mongolia from 1982 to 2006

The NDVI changes over the last 24 years for July and August are depicted in Fig. 11.5. The NDVI values don't show a significant trend before 1994. However, from 1994 onwards, a decreasing trend can be observed. This trend can be observed in all natural zones and, in desert steppe and desert zones, the NDVI values are even dropping below the 0.06 threshold of no vegetation (i.e. bare soil).

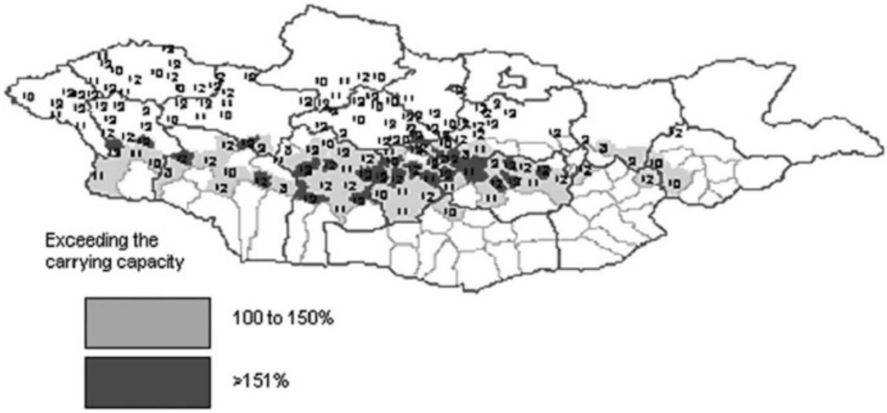

Fig. 11.6 Over grazing is serious and often exceeds 150 % of the assessed carrying capacity

Typically, the causes of land and pasture degradation are various. The Agency of Land Affairs, Geodesy and Cartography carried out a study on the state and quality of pasturelands in Mongolia and found that more than half of the pasture area was degraded to some extent. There are different reasons for the degradation but the main factor causing pasture degradation is overgrazing (Fig. 11.6).

Disturbance from mining, uncontrolled vehicular access to the rangelands, damage from rodents, sand movement, and water erosion are also significant contributors to land degradation. In the next 40–50 years, many *soums* (sub-provinces) in the territory of the Bayan-Ulgii and Khovd provinces (in the western region of Mongolia) will increasingly be affected by desertification, because the amount of precipitation will decrease and average temperature will increase.

Herders are living under direct risk of weather and climate. Local officials and 97.6 % of the herders consider climate change and environmental change a reality in their area. When asked which aspects of their environment and climate had changed most significantly they named various elements including heavy snowfall, reduction of drinking water, frequent drought and *dzud* events, drying up of rivers and springs, reduction in hay making yield, reduction of feeding value of pasture land, sand movement and intensification of desertification. The herders also noted a decrease in the number of forage plant species, animal fatness and bodyweight, and consequently a reduction in the production of meat and milk as well as wool, cashmere and molt hair.

Also, because of decreased permafrost, perpetual snows, glaciers, lakes, streams and rivers that have their origin in the Khangai Mountain range, will lose their headwater and will eventually dry up completely. They will only have seasonal and temporary flow dependent on precipitation levels. Furthermore, the decrease in permafrost in combination with changing rainfall patterns, will very likely result in an increase in the number of forest fires. Taken together, most of the studies conclude that climate change will negatively impact the natural resource base in Mongolia and will consequently further aggravate the precarious conditions in which rural communities are living (Mearns 2004).

5 Government Response to Perceived Threats

5.1 Legislative and Regulatory Response

In response to these and other observations, the government of Mongolia has started to formulate legislation and policy measures to prepare itself for the possible consequences of climate change. In 1993, the government ratified the United Nations Framework Convention on Climate Change (UNFCC) and in 2001 it approved a National Action Program on Climate Change. In addition, several policy documents have been put in place that are directly or indirectly related to climate change. These include:

- Laws on Nature and Environment; Laws on Meteorology, Hydrology and Environmental Monitoring; Laws on Land; Laws on Arable Farming; Laws on Disaster Prevention; Laws on Pasture;
- A program on sustainable development of Mongolia, 1999;
- A national program on preventing livestock from drought and *dzud* disasters, 2001;
- A food program on food supply, security and nutrition, 2001;
- A program on supporting development of intensive livestock-farming, 2003;
- A state policy on the development of food and agriculture; and
- Relevant annual reports on the natural and environmental review in Mongolia.

The government has also established an inter-disciplinary and inter-sectoral National Climate Committee (NCC), led by the Minister for Nature and the Environment, to coordinate and guide national activities and measures aimed at adapting to climate change. High-level officials such as Deputy Ministers, State Secretaries and Directors of the main departments of all related ministries and agencies are members of the NCC.

Mongolia is a party to the UN Convention on Combating Desertification (UNCCD) since 1996. As part of UNCCD, Mongolia developed National Action Plans (NAP) 1996 and 2003. The new government developed the national action plan (2010–2020) for combating desertification that was approved parliament in 2011. Also, development of a new Pasture Law is in progress. In the implementation framework of these two NAPs, the Government of Mongolia focused on national capacity building for combating desertification and the creation of a more viable policy and legal environment to take real action. The national legal framework has been strengthened by a number of new or modified laws regarding ecosystem management.

5.2 Legal and Regulatory Environment to Combat Desertification

The main legal documents related to combat desertification are the National Action Plan to combat desertification (NAP CD2) and the Pasture Law. NAP CD 2 was approved by the Government of Mongolia in 2011. Different regulations regarding pastureland management exist in the "Land Law", "Nature Conservation Law" and "Law on Natural Plant". A new "Pasture Law" was developed by Ministry of Agriculture and Light industry, but in 2011 it is was not yet approved.

5.2.1 National Action Plan to Combat Desertification (NAP CD2)

The reason for formulating a new National Action Plan to Combat Desertification (NAP CD 2010–2020) is the limited impact of the two former NAPs. Considering the gravity of the problem, there is a need to address desertification in a different and much more resolute way.

The new National Action Plan has the following five components:

- Institutional strengthening;
- Policy and legal framework reform;
- Science, technology and knowledge integration;
- Advocacy, awareness raising and education promotion;
- Implementation of concrete actions at the grassroots level;

Every component has an operational objective and actions in order to reach objectives of each component.

6 Formulating Adaptation Measures

Many of the adaptation measures that have been formulated in the past, were often characterized by their generic approach and in many cases little thought went into how they can be financed and implemented. Furthermore, adaptation measures are often formulated without taking into consideration other drivers of change. The debate about climate change vulnerability, for instance, has caused a lot of discussions in Mongolia about whether or not the government should stimulate a shift from traditional livestock activities towards an economy based on farming. However, traditional livestock activities are not only under pressure from climate change but are also influenced by other socio-economic developments, such as the increased demand for cashmere. Without understanding these broader developments, it is hard to develop appropriate policies for dealing with the problems that people are facing (Bedunah and Schmidt 2004).

A donor-funded land management project in the rangelands of Mongolia's Gobi desert was designed to create both conservation and livelihood benefits. This GTZ project ran from 1995 to 2006, Leisher et al. (2012) report increased household income and increased rangeland productivity and attribute the success of the project to the incorporation of community-based management into the design. The project created community organizations (CBO) to improve pasture management, develop alternative livelihoods, and strengthen cooperation among local communities, and district governments. Improved pasture management included coordinating the moves on and off pastures for all participating herders, improving water sources for livestock, and developing specific winter grazing areas for CBO members. The development of CBO was supported by locally hired community organizers who were part of the project staff. There was one community organizer in each district, and their role was to organize and encourage the communities and act as a liaison with local government, resource agencies, and the rest of the project team. The project ran for more than 8 years, comprised 12 districts across 3 provinces, and covered 13.5 Mha. When funding support to the project ended in 2006, 83 CBOs had emerged, involving 1,175 households, or about 14 % of the households in the project area.

Other success stories have been reported. Mostly from bi-lateral co-operation (principally with the Republic of Korea and with China). Both of these donor countries are concerned about the dust problem which plagues the eastern seaboard of China and the Korean peninsular and Japan (Squires 2007) but protection of infrastructure such as the railway line from Ulaanbaatar to Zamyt-Ud on the border with China is another priority and desertification control measures have been applied to stabilize dunes and prevent entrainment of sand and dust using methods outlined in Chaps. 2 and 3 (this volume).

Apart from measures designed to prevent land degradation there is also effort directed at reducing the grazing pressure by improving the supply of forage. An example of a successful approach is outlined in Box 11.1.

Box 11.1: GL-CRSP GOBI Forage Project: A Success Story

GOBI Forage Project* has been operating from 2004 to 2008. The ability of the project…to produce current and accurate maps showing forage conditions 30 and 60 days into the future has proven exceptionally valuable to herders and those with a stake in rangeland management. It has also had a transformational impact on the thinking of Mongolian Government Ministries and donors working in rural development sector It has been described, as a cutting-edge project that has established a forage monitoring and forecasting service that regularly delivers map information to pastoral communities, policy makers and administrators responsible for agriculture and rural development. Successes in the project were derived in part from the Project's ability to successfully carry out four complementary activities: (i) adapting the

(continued)

Box 11.1 (continued)
technology for measuring forage quantity to local conditions; (ii) conducting detailed field measurements of forage quality; (iii) information outreach (extension); and (iv) linking information with herder alliances. The way [the technology] was applied in Mongolia was truly seminal, and the impact on the ground was dramatic. Many of the herders, provincial administrators, and technical specialists that were originally sceptical about the feasibility of obtaining accurate forage prediction maps are now impressed by the high quality predictive capacity of project technology and efficient information dissemination protocols. An increasing number of government officials are using Gobi Forage radio broadcasts (part of the outreach effort) to obtain information about pasture conditions and to guide their recommendations on livestock movements. Some 93 % of government officials who use Gobi Forage products now indicate that those products are "very useful" for their work. One provincial governor described how the system helped him manage the influx of some 50,000 herders and their families from a neighboring drought-stricken province and prevent conflict with local herders. While perceptions of the accuracy of the forage information vary widely among herders themselves, use of the technology is increasing, with almost 50 % of herders claiming that the data had informed their decision-making. It isn't only the livestock raisers who benefited here. Use of GOBI Forage technologies by soum (county) and aimag (province) officials has proved fundamental in the management of human populations and livestock across political boundaries during times of drought and harsh winter conditions. As virtually all significant short term movements of human populations are related to forage conditions, the map resources generated by the GOBI technology suite assist in pastoral migration management, greatly enhancing the capacity for improved natural resource management and institutional operation. The technology and its application has also transformed how some of the main government institutions responsible for agriculture – including, but not restricted to forage monitoring – operate and, more importantly, how well they operate.

*http://glcrsp.ucdavis.edu

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Chapter 12
Arid Land Development and Combating Desertification in Pakistan

M. Shahbaz, Muhammad Khalid Rafiq, and Taj Naseeb Khan

Synopsis This chapter outlines the situation in Pakistan and traces the history of Pakistan's efforts to fulfill its obligations under the UNCCD. Legislation and institutional arrangements were put in place to underpin the efforts. Some technological interventions to address the issues of desertification have been successfully implemented in different parts of Pakistan. Some of these include; Rangelands Utilization Model in Pothwar Plateau, Gully Land Management through Soil Conservation and Water Harvesting, Range Improvement through Community Participation, Salinity Control and Reclamation of Affected Areas, Rehabilitation of Desert Ranges through Reseeding, Sandune stabilization through shelterbelt technology in Thal desert, Forage Reserve Establishment in Arid Highland Balochistan, Reclamation of salt-effected areas, Desertification Control in Cholistan and Restoration of Land Productivity in Barani Lands.

Key Points

- Desertification is a major problem in Pakistan. The country is faced with problems of environmental degradation, loss of soil fertility, loss of biodiversity and reduction in land productivity resulting in increased poverty of local communities. Recognizing the seriousness of the problem, Pakistan signed the UNCCD in 1994, and ratified it in 1997, thus becoming a Party to it. A National Action Program to Combat Desertification (NAP) in Pakistan has been prepared. Ministry of Environment took initiative in the development of the PDF-B phase to design a full-scale project called "Sustainable Land Management Project" (SLMP).

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- The two most important driving forces of land degradation in Pakistan are limited land resources and population increase. The result is small farms, low production per person and increasing landlessness. A consequence of land shortage is poverty. Land shortage and poverty, taken together, lead to non-sustainable land management practices, the direct causes of degradation. Poor farmers are led to clear forest, cultivate steep slopes without conservation, overgraze rangelands and make unbalanced fertilizer applications.
- Agriculture has been and continues to be the principal driving force of the national economy, accounting for 26 % of GDP and, together with agro-based industries, contributing 80 % of export earnings. Over half of the labor force is absorbed by the sector, which has been performing below potential as a result of various technical, social and structural constraints. The sector as a whole is passing through a transitional phase from subsistence to increasingly commercial production. There is, however, a gap between the well-resourced commercial sector with large holdings and access to reliable irrigation and the traditional sector, which includes farmers with small subsistence holdings whether irrigated, or Barani, tenants and physically marginal farms outside the Indus basin.

Keywords Desertification • Land degradation • Resources-utilization • Irrigation • Rangelands • Snow melt • Biodiversity • Salt affected land • Hindu Kush • Sindh • Balochistan • Waterlogging • Forest

1 Introduction

Pakistan, with a great variety of landscapes has a diversified relief including the majestic high mountain ranges of the Himalayas, Karakorams and Hindu Kush, snow-covered peaks, eternal glaciers, and the inter-mountain valleys in the north, vast rich irrigated plains in the Indus basin, stark deserts and impressively rugged rocky expanse of plateaus in the south-west of Balochistan.

The country is characterized by a continental type of climate, which is arid and semi-arid (Fig. 12.1). There is an extreme variation in temperature depending on the topography of the country, which experiences an overall deficiency in rainfall. One-fourth of the country's land area, which is suitable for intensive agriculture, is seriously subjected to wind and water erosion, salinity/sodicity, water logging, flooding and loss of organic matter. Watersheds in upper Indus and its tributaries suffer from unfavorable soil and moisture regimes. Accelerated surface erosion due to deforestation in the catchments is reducing the life of Tarbela and Mangla reservoirs, which provide water for 90 % of the food and fiber production in the country.

Outside the Industrial basin, water mining without ground water recharge has resulted in sharp declines in water table in areas like Balochistan. Over-exploitation and misuse of rangelands extending over a vast area are seriously constraining livestock production, thus adversely affecting the livelihood of pastoral communi-

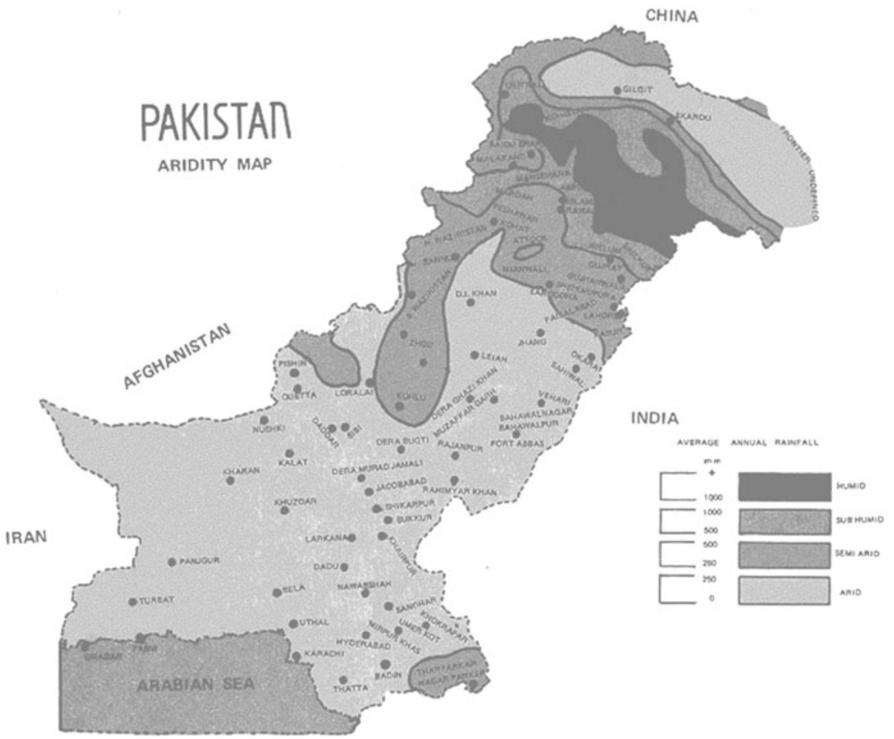

Fig. 12.1 Map of Pakistan showing distribution of rainfall. The darker areas receive higher rainfall

ties. The arid coastal strips and mangrove areas are under increased environmental stress from reduced fresh water flows, sewage and industrial pollution and over-exploitation of other natural resources. The rate of land degradation in the fragile ecosystems like sandy deserts, Rod Kohi and coastal areas is accelerating, rendering many areas unproductive and threatening the agricultural economy of the country.

Keeping in view the growing problems of desertification in Pakistan the UNCCD Convention was signed in 1994 and ratified in 1997. Pakistan thus became a Party to it and fulfills the obligation under UNCCD. As a result, a NAP has been prepared with the financial and technical support of United Nations Environment Program (UNEP) and Economic and Social Commission for Asia and Pacific (ESCAP). Pakistan Agricultural Research Council through its Range Research Institute (RRI) was entrusted to develop the NAP in Pakistan. A multi-disciplinary team comprising of experts of various relevant disciplines drafted the NAP after a series of discussions and consultations with UNEP/ESCAP and relevant federal, provincial agencies and NGOs. The first draft of NAP was discussed in a national workshop organized by PARC/RRI which was attended by all relevant organizations. Recommendations of the workshop were incorporated in the draft and submitted to the Ministry of Environment. This draft was again discussed in a national seminar

Table 12.1 Distribution of arid region in Pakistan (square kilometers)

Province	Arid	Semi arid	Sub humid	Other	Total area
Punjab	119,310	59,678	17,014	10,197	206,199
Sindh	134,896	6,018	–	–	140,914
Balochistan	149,467	19,723	–	–	347,190
NWFP	6,194	16,491	15,160	36,676	74,521
FATA	–	13,580	11,239	2,401	27,220
Total	409,867	115,490	43,413	49,274	796,044

Source: Sustainable Agriculture, NCS Sector Paper by Dr. G.R. Sandhu

organized by the Ministry of Environment which made suggestions according to the change environment and ecological scenarios, which were incorporated in the NAP by RRI. The second draft was circulated to more than 60 relevant organizations by the Ministry of Environment for their views/comments. The written input received from various organizations/individuals was again incorporated by RRI and third a draft was sent to the Ministry of Environment in January 2001. The final draft has been finalized after a long drawn-out process of consultation with professionals from federal, provincial and international agencies and NGOs operating in Pakistan. The action program has been prepared in line with UNCCD guidelines.

The NAP calls for a systematic and comprehensive area-development approach with people's participation at grassroots level with a bottom-up mechanism for sustainable management of the natural resources in fragile eco-systems so as to combat desertification and halt land degradation.

1.1 Present Status

Pakistan is predominantly an arid to semi-arid country with 68 Mha of land lying in regions where the annual rainfall is less than 300 mm. The extent of arid regions in various provinces of the country is shown in Fig. 12.1 and Table 12.1.

1.2 Status Quo Scenario – Land, Population and Desertification

The two most important driving forces of land degradation in Pakistan are limited land resources and population increase. The result is small farms, low production per person and increasing landlessness. A consequence of land shortage is poverty. Land shortage and poverty, taken together, lead to non-sustainable land management practices, the direct causes of degradation. Poor farmers are led to clear forest, cultivate steep slopes without conservation, overgraze rangelands and make unbalanced fertilizer applications.

1.3 Resource Picture

Out of 79.6 million ha area of the country, only 20 million ha are available for farming. Irrigated agriculture is practiced on 16 million ha and the remaining 4 million ha are under rainfed (*Barani*) farming. A sizeable chunk of the landmass, about 31 million ha, is under forests and rangelands and /or remains untapped. The land use data for the last decade shows that the total area under cultivation remained static (GOP 2003).

1.4 Rural Poverty

Poverty is widespread in Pakistan, and is predominantly a rural phenomenon. Nearly two-thirds of the population lives in rural areas. Most rural poor people depend on agriculture for their livelihoods. Many have inadequate access to basic services such as safe drinking water, primary health care, education and other social services.

Poverty rates fell in the 1970s and early 1980s but rose again towards the end of the 1990s. According to the Government of Pakistan's poverty reduction strategy paper, currently about 10 % of the population is chronically poor, but a much larger part of the population (about 33 %) is considered vulnerable and likely to sink into poverty in the event of an external shock such as drought or earthquake. More than one-third of the total households in the country were below the poverty line. The level for some rural areas being close to 40 %. Most of the land in Pakistan is arid, semi-arid (Fig. 12.1) or rugged, and therefore not easily cultivated. Water resources are scarce throughout most of the country, and providing more remote rural communities with a reliable water supply is difficult.

1.5 Land-Holding Distribution

The agricultural census data (Table 12.2) reveals interesting patterns of land distribution in Pakistan. Over 80 % of the farms in provinces except Balochistan are less than 10 ha in size and these occupy about 65 % of the total farm area. It is important to note that while only 2 % of all farms are of bigger size – more than 20 ha – they occupy over 14 % of the total farm area. In Balochistan, these large farms constitute a much larger proportion of all farms and command 46 % of all farm area. Following are the three general farm /tenure systems practiced in Pakistan (Table 12.3).

1. Farms cultivated by owners.
2. Farms partly cultivated by owners and partly cultivated by tenants.
3. Farms cultivated entirely by tenants (sharecroppers).

Table 12.2 Current land use in Pakistan based on satellite imagery interpretation (000 ha)

Forest cover/land use class	Ajk	Balochistan	Northern areas	NWFP	Punjab	Sindh	Total
Forest/trees							
Conifer	16	42	660	940	30		1,913
Scrub	1	504		539	132		1,191
Riverain		20		13	27	112	173
Mangrove		2				205	207
Irrig. plantation	7	1			79	23	103
Farmland trees		23	6	70	306	54	466
Linear planting	10			2	14		16
Misc. planting	241			120	20	5	155
Total	275	592	666	1,684	608	399	4,22
Agriculture							
Irrigated	6	1,177	44	993	10,743	5,705	18,668
Rainfed	36	3	4	553	1,316		1,912
Total	42	1,180	48	1,546	12,059	5,705	20,580
Rangelands							
Degraded	731	11,674	896	4,106	4, 466	2,809	24,682
Non-degraded		892		519	1,293	68	2,772
Alpine	79		705	269			1,053
Total	810	12,566	1,601	4,894	5,759	2,877	28,507
Barren land							
Snow/glacier			27				27
Rock, gravel		17,516		138	337	523	18,514
Desertic		2,802			1,324	3,759	7,885
Tidal flats		54				413	467
Total		20,372	27	138	1,661	4,695	26,893
Water bodies							
Riverbed				48	400	155	603
Lake		5	1	1	1	41	49
Dam, reservoir	19	1		15	49	54	138
Swamp					27	96	123
Total	19	6	1	64	477	346	913
Urban		3		4	62	69	138
Unclassified							
Above 3,650 m	184		3,161	1,792			5,137
Below 3,650 m			1,536	52			1,588
Total	184		4,697	1,844			6,725
All land classes	1,330	34,719	7,040	10,174	20,626	14,091	87,980

Source: Forestry Sector Master Plan (1992)

The tenure distribution of farms of various sizes is shown in Table 12.4. Most of the small farms are cultivated by owners except in Sindh where tenants seem to dominate. Part owner and part tenant cultivation is quite common in Punjab and NWFP, particularly on farms of medium sizes. Over 68 % of the large farms (20 ha)

Table 12.3 Farm size distributions in Pakistan

	Farm number		Farm area	
Farm size (ha)	Million	%	Million	%
<0.5	0.68	13	0.19	1
1 < 2	1.04	20	1.45	8
2 < 10	2.32	46	9.41	49
10.0 < 20	0.24	5	3.03	16
20.0 < 60	0.09	2	2.61	14
>60	0.02	–	1.94	10

Source: Agricultural Statistics of Pakistan 1998–1999

Table 12.4 Distribution of farms and farm area by tenure

	Farm number (%)			Farm area (%)		
Farm size (ha)	Owner	Owner-tenant	Tenant	Owner	Owner-tenant	Tenant
<0.5	90	1.0	9.0	88	2	10
<2.0	75	7.5	17.5	75	7	18
2.0 < 10	59	18	23	59	18.5	22.6
10.0 < 20	63	24	13	62	25	13
20.0 < 60	72	21	7	72	21	7
>60	79	16	4	81	16	3

Source: Pakistan Census of Agriculture (1990)

and their area are owner-operated in Sindh and Balochistan. The land ownership data, which are based on land records, are not readily available for recent years. However, land concentration was quite high in Sindh and quite low in NWFP. In fact, in Punjab and NWFP, very high percentage of farm area was in the hands of owners of 10 ha or less.

1.6 Agriculture Milieu

Agriculture has been and continues to be the principal driving force of the national economy, accounting for 26 % of GDP and, together with agro-based industries, contributing 80 % of export earnings. Over half of the labor force is absorbed by the sector, which has been performing below potential as a result of various technical, social and structural constraints. The sector as a whole is passing through a transitional phase from subsistence to increasingly commercial production. There is, however, a gap between the well-resourced commercial sector with large holdings and access to reliable irrigation and the traditional sector, which includes farmers with small subsistence holdings whether irrigated, or Barani, tenants and physically marginal farms outside the Indus basin.

Rural sector in Pakistan is going through a structural change. Although there has been a constant increase in the number of non-farm families in relation to the number of farm households, a substantial increase in the share of small farms in the total farm households and a decline in the number of tenant-operated farms is significantly visible. This change is resulting from “push” factors, such as farm mechanization, displacing tenant and agricultural workers, as well as from "pull" factors stemming from a growing and increasing diversified rural sector offering groups of farmers more opportunities for off-farm work.

1.7 Resource Utilization

Of the total surveyed area, about 20 % of the land is potentially good for intensive agriculture, about 2.4 % of the land has medium to good potential for forestry and bulk of the land (62 %) either lacks or has low potential for crop /forestry production and is primarily used for livestock grazing. The data presented in Table 12.5 indicate the land use pattern since creation of Pakistan. During the five decades (1947–1997), the reported area witnessed an upward trend by 12.18 million ha. During the same period, the total cropped area was expanded to a total of 10.6 million ha of which 4.4 million ha were due to expansion of irrigated cropping to new areas and the balance was the outcome of intensification or double cropping.

The increment in the total cropped area has been remarkably steady as a result of the tendency for irrigation to be expanded to large discrete blocks. The expansion phenomenon kept on occurring for the first two decades (1947–1967), accounting for 79 % of the increase in cropped area. In 1973–1977 it accounted for only 33 % of the increment in total cropped area. Since 1972, intensified farming has become the principal source of increasing crop yield supported with the availability of an array of modern inputs and technical interventions, and supply of additional irrigation water through tube-wells.

2 Desertification

Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Land degradation means reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as (i) soil erosion caused by wind and/or water (ii) deterioration of the physical, chemical and biological or economic properties of soil and (iii) long-term loss of natural vegetation (UNCCD).

2.1 Desertification in Pakistan

There is a serious problem of desertification in many parts of the country. Northern mountains of Pakistan are the major source of water for Tarbela and Mangla Dams.

Table 12.5 Land utilization in Pakistan (million hectare)

Land use	1947–1948	1958–1959	1963–1964	1968–1969	1973–1974	1978–1979	1983–1984	1988–1989	1996–1997	1998–1999
Reported area	46.33	49.46	52.20	53.22	54.09	54.82	58.18	57.90	59.23	59.28
Forest area	1.38	1.46	1.92	2.31	2.83	2.82	2.96	3.43	3.58	3.60
Not available for cultivation	20.73	19.76	18.57	20.13	20.74	20.28	22.36	24.06	24.61	24.52
Cultivable waste	9.19	11.25	13.00	11.53	11.00	11.51	12.53	9.39	9.06	9.29
Current fallow	3.74	3.90	4.81	4.76	4.69	4.77	4.67	4.93	5.48	5.10
Net area sown	11.27	13.09	13.90	14.49	14.83	15.43	15.66	16.09	16.50	16.77
Sown more than once	1.04	1.52	1.89	2.14	2.95	3.78	4.33	5.73	6.73	6.19
Total cropped area	12.31	14.61	15.79	16.63	17.78	19.22	19.99	21.82	22.73	22.96

Source: Agricultural statistics of Pakistan, Islamabad

However, due to heavy soil erosion, caused by deforestation in the catchments, these reservoirs are silting up, thus reducing the capacity of power generation and availability of irrigation water. Barani lands are subjected to heavy soil erosion, primarily due to improper land use by crop cultivation, livestock grazing and illegal removal of vegetation cover. Deserts have acute problems of shifting sand dunes and salinity. The irrigated areas are infested with the twin-menace of water logging and salinity. Because of mismanagement of Suleiman Rod Kohi areas, there is substantial damage to crops and property by flash floods. Underground water resources in western dry mountains of Balochistan are shrinking, due to very little recharge, overexploitation of the meager quantity of water for horticulture and crop cultivation. The productivity of rangelands is hampered by heavy livestock pressure. The arid coastal strips and mangrove areas are under increased environmental stress from reduced fresh water flows, sewage and industrial pollution and overexploitation of other natural resources.

2.2 Key Issues Related to Desertification

- *Water erosion*
- Wind erosion
- Depletion of soil fertility
- Deforestation
- Livestock Grazing Pressure
- Loss of Biodiversity
- *Water logging and Salinity*
- *Drought and Flooding*
- *Socio-economic constraints*

2.3 Extent of Desertification

According to Shah and Arshad (2006) the nature, geographic extent and severity of desertification is reaching alarming proportions. The extent of area affected by salinity and sodicity is presented in Table 12.6. In the majority of the soils on the plains in Pakistan, the rainfall is usually low and the evapotranspiration is higher than the annual precipitation resulting in build up of salts in the soil profile and their accumulation on the soil surface. At country level, 6.28 million ha of area is affected with salinity and sodicity. The majority of salt-affected soils are saline-sodic in nature. These salt affected soils are causing potential reduction in yield. Salinity and sodicity are associated with irrigation but these also occur as a consequence of soil formation process over the centuries. At present over 2.8 million ha are affected by salinity/sodicity in Pakistan. Water logging, salinity and sodicity have reduced the drainage capacity of the soils resulting in lower soil fertility, decline in crop yields and loss of biodiversity.

Table 12.6 Soils affected by various types of salinity and sodicity (000 ha)

Type of Soil	Punjab	Sindh	NWFP/FATA	Balochistan	Pakistan
Soils with surface/patchy salinity and sodicity					
Irrigated	472.4	118.1	5.2	3.0	598.7
Un-irrigated	–	–	–	–	–
Gypsiferous saline/saline-sodic soils					
Irrigated	152.1	743.4	–	76.6	972.1
Un-irrigated	124.5	536.3	–	160.1	820.9
Porous saline sodic soils					
Irrigated	790.8	257.0	25.7	29.4	1102.9
Un-irrigated	501.0	150.1	7.8	364.0	1022.9
Dense saline sodic soils					
Irrigated	96.7	32.5	0.9	–	130.1
Un-irrigated	530.0	379.7	8.9	714.8	1633.4
Total:	2667.1	2217.1	48.5	1347.9	6281.0

Table 12.7 Area affected by water erosion (000 ha)

	Province					Total
Degree of erosion	Punjab	Sindh	NWFP/FATA	Balochistan	Northern area	Pakistan
Slight (sheet and rill erosion)	61.2	–	156.3	–	180.5	398.0
Moderate (sheet and rill erosion)	896.8		853.8	1805.0	25.8	3581.4
Severe (rill, gully and/or stream bank erosion)	588.1	58.9	1765.1	829.6	504.2	3745.9
Very severe (gully, pipe and pinnacle erosion)	357.9	–	1517.0		1571.6	3446.5
Total	**1904.0**	**58.9**	**4292.2**	**2634.6**	**2282.1**	**11,171.8**

Source: Soil Survey of Pakistan. N.d. Reconnaissance Soil Survey Reports from 1965 to 1988, Lahore

2.4 Soil Erosion

Soil erosion implies loss or removal of surface soil material through the action of moving water, wind or ice. The extent of the area affected by water and wind erosion is given in Tables 12.7 and 12.8 respectively. About 13.05 million ha of area is affected by water erosion and about 6.17 million ha is affected by water erosion. Soil erosion is taking place at an alarming rate and is mainly due to deforestation in the north. Water erosion is prominent on steep slopes such as the Potohar track and surrounding areas, an area extensively used for cultivation. The highest recorded rate of erosion is estimated to be 150–165 tons/ha/year. The Indus River carried the fifth largest load of sediment (4.49 tons/ha) in the world in 1990. According to some

Table 12.8 Area affected by wind erosion (000 ha)

Degree of erosion	Province: Punjab	Sindh	NWFP/FATA	Balochistan	Northern area	Total Pakistan
Slight	2251.4	295.0	13.1	36.0	–	2595.5
Moderate	279.1	70.2	3.8	143.6	–	496.7
Severe to very severe	1274.0	1686.8	19.6	100.9	–	3081.3
Total	**3804.5**	**2052.0**	**36.5**	**280.5**	**–**	**6173.5**

Source: Reconnaissance Soil Survey Reports from 1965 to 1988

estimates the Indus is adding 500,000 tons of sediment to the Tarbela Reservoir every day, reducing the life of the dam by 22 % and the capacity of reservoir by 16 %.

Water erosion: The soils in the Indus basin are recent and undeveloped. The surrounding mountains have some of the world's steepest and largest slopes. Intense summer rainfalls along with melting of snow in high mountains contribute to the soil erosion hazards. Land use practices, vegetation cover, soil type and structures are other major factors related to soil and water erosion.

In the northern mountainous areas with steep slopes, the water erosion is low in the areas with permanently closed canopy forests, while the erosion is greater in areas with arable crops on steep slopes. About 11 million ha are affected by water erosion.

Sedimentation of canal irrigation system decreases water and land use efficiency. Some 40 million tons of soils are brought into the Indus basin each year. It shortens the life span of major reservoirs and reduces their efficiency. The upstream riverside infrastructure is destroyed and top soil is washed away declining productivity of the area. In downstream, the sediment reduces the efficiency of hydropower generation and irrigation systems.

Wind erosion: Land degradation by wind erosion is quite common in the sandy deserts of Thal, Cholistan, Tharparkar and sandy areas along Mekran Coast. Erosion is significant in areas around habitations and watering points trampled by livestock. Here the major degrading factor is the overexploitation of rangelands for fuel-wood cutting and livestock grazing. The global impact of wind erosion is prevalent in areas where sand dunes are leveled for irrigated cropping. These areas have assumed the form of 0.5–4 m high moving sand dunes, posing danger for cultivated land and infrastructure. Some 3–5 million ha are affected by wind erosion (Table 12.8). The amount of soil removed by wind is about 28 % of total soil loss. High velocity wind storms cause severe movement of sand dunes depositing thick layer of sand on roads, railway tracks, croplands and threaten village inhabitants.

Deforestation: There is only 5.2 % area under forests, which is too low to meet environmental as well as socio-economic needs of the country (Table 12.5). Due to deforestation, forest cover is shrinking by 3.1 % annually and woody biomass by 5 % annually. Natural vegetation reduces sedimentation in water reservoirs and stabilizes sand dunes. The continuous destruction of forests is causing a substantial loss. The declining rate of woody biomass is the second highest in the world. It ranges between 4 and 6 % per year. Almost 7,000–9,000 ha are deforested every year and this rate is especially severe in the north where the per capita consumption for fuelwood is ten times higher due to the ruthless winters.

Mangrove forests protect the port of Karachi against wave action and act as nursery for shrimp. Mangroves are now under threat. Every major type of forest or protective cover in Pakistan has suffered heavily in the recent past from indiscriminate cutting, overgrazing, poor management and man-made ecological changes. This has increased desertification, erosion and silting of reservoirs and biological defenses against water logging and salinity are also deteriorated. The ability to resist against soil erosion caused by monsoon rains is largely dependent on vegetation and vigor of vegetation at ground level. Soil erosion increases on degraded grazing land with sparse vegetation cover, which leads to siltation of rivers and channels. Soil fertility declines due to removal of top soil resulting in low production of forage, fodder, fuel wood, timber and grains. Soil erosion in the watershed areas of rivers increases sedimentation load, which reduces the storage capacity of dams.

Livestock Grazing Pressure: Uncontrolled grazing of livestock is extremely destructive to forest and vegetation cover. With the increase in livestock population there is heavy pressure on natural vegetation. During period of feed scarcity, thousands of cattle, sheep and goats depend on fodder plants, which are lopped to the main stem. Unregulated livestock grazing reduces the productivity of rangelands due to soil compaction, devegetation of fragile slopes, destruction of terraces and selective destruction of growing trees and shrubs. As economy in desert regions is pastoral, it affects both livelihoods of the desert dwellers as well as influences the fragile environment.

Loss of Biodiversity: Due to ever increasing human and livestock population there is enormous pressure on natural vegetation in almost every agro-ecological region of the country. Overgrazing of rangelands has extensively decreased the carrying capacity. Some areas have also been affected by water logging and salinity damaging the natural flora. Aridity and prolonged drought in arid lands have affected the vegetation cover in these areas. All these factors have contributed towards the loss of biodiversity in various regions of the country. As a result of degradation of natural habitat as well as illegal hunting, 31 species of mammals, 20 species of birds and 5 species of reptiles are listed as endangered in the country.

Water logging and Salinity: The major factor contributing to water logging in cultivated areas is excessive percolation (leakage) from the canal system, which builds up the ground water level.

The extent of waterlogged area is given in Table 12.9. The figures are based on the surveys which were completed in the late 1990s. It appears that problem of water logging may not be as serious now as it was in the past. The problem has reduced due to prolonged drought and excessive mining of ground water.

The human activities such as cultivation of high delta crops on highly or moderately permeable soils, obstruction of natural drainage channels through

Table 12.9 Extent of water logged area (000 ha)

Water table depth	Punjab	Sindh	NWFP/FATA	Balochistan	Pakistan
(a) Cultivated area	685.8	508.6	90.7	142.1	1427.2
100–150 cm	239.2	39.4	39.7	[a]	318.3
50–100 cm	78.6	189.2	20.7	4.3	292.8
Less than 50 cm	368.0	280.0	30.3	137.8	816.0
(b) Uncultivated area (less than 150 cm)	10.0	116.0	1.1	15.6	142.7
Total	695.8	624.6	97.8	157.7	1569.9

Source: ECO Services International (2006)
[a]Negligible extent

construction of buildings and roads, improper alignment and poor maintenance of artificial open drainage system, inefficient disposal of excess rain water *etc*. also add to water logging problem. Total waterlogged area with water table depth of 2–3 m in Pakistan is about 11 million ha.

Drought and Flooding: Drought is a temporary feature caused by anomalies in the usual climate of the region. It occurs in virtually all-climatic regimes, but with higher frequency and probability in the arid and semi-arid regions. Periodic droughts are seen as a major cause of desertification in several desert areas of Pakistan. The provinces of Balochistan, Sindh and southern Punjab have been severely affected due to prolonged dry spell in the early years of the new century. It is estimated that 2.2 million people and 7.2 million heads of livestock have been affected. The effects and impact of drought in fragile eco-systems assume serious proportion due to misuse of marginal areas and unwise land use practices and overexploitation of natural resources. Adverse effects of drought on human activity last for many years.

Flood occurrence could be an occasional or regular feature of the region. Being an arid to semi-arid country, floods are usually caused by excessive precipitation particularly during monsoon season due to weather and climatic disturbance. Major floods in 1973 and 1992 caused severe damage to the national economy resulting in land degradation and loss of biodiversity. Floods prohibit cultivation in summer season, destroy farm houses and other facilities and bury fertile top soil under relatively infertile sediments.

Socio-economic constraints: Pakistan with a population of over 130 million is ranked 7th most populous country in the world with a growth rate of 2.6 % per annum. The implications of such a rapid population proliferation are grave and multifaceted. It adversely fosters the process of sub-division and fragmentation of farmlands and adds to the fragile and marginal lands by denudation of forests and rangelands. There is massive migration from rural to urban areas. It is the poorest of the poor who suffer from desertification and drought. Unless properly managed, the already degraded resources will be under heavy pressure. Agriculture, forestry, hunting and fishing account for 66 % of the rural work force. Over half of the labor force is engaged by agriculture sector, which has been performing below potential due to various technical, social and structural constraints.

3 Proven Practices – Examples from Remediation Efforts Attention Has Been Given in Each of the Major Climate Zones to Methods to Restore Degraded Lands or Increase Productivity. Examples of Some of These are Shown Here (Figs. 12.2, 12.3, 12.4, 12.5, 12.6, and 12.7)

Fig. 12.2 Sprinkler irrigation for fodder production

Fig. 12.3 Shelterbelt technology to combat sandune shifting in Thal Desert

Fig. 12.4 Dry afforestation technology in Thal

Fig. 12.5 *Eucalyptus* wind break in desert

4 Conclusions

Land degradation, which includes both desertification and deforestation, is occurring worldwide, with the most severe impact on the poorest rural communities. As a result, agricultural productivity is declining sharply, while the number of mouths to feed continues to grow. In an attempt to meet the food and fiber needs of ever growing population of Pakistan, the Green revolution concept was introduced and as a result high yielding varieties and new cropping techniques were adopted in the irrigated parts of the country. Whereas on the other hand, Pakistan is predominantly a dry land country where 80 % of its land area is arid or semi-arid, about 12 % is dry sub-humid and remaining 8 % is humid. Increase in population and greater

Fig. 12.6 Improved community rangeland in Balochistan

Fig. 12.7 Jatropha plantation on marginal lands for biofuel production

competition for improved crop production has placed lot of pressure on largely fragile areas. As a result country is faced with the daunting challenges of land degradation and desertification.

There is need to build capacity for the implementation of the NAP process. This is because the implementation of NAP will require inter-agency cooperation for joint programs, plans and projects and in some cases joint implementation and day-to-day operational coordination. In order to meet the challenges of land degradation and desertification in Pakistan, the Ministry of Environment took the initiative in development of the PDF-B phase to design a full-scale project called "Sustainable Land Management Project" (SLMP) funded by GEF-UNDP. The SLMP would help in improving ecosystem resilience and productivity through promoting sustainable use of land resources, mainstreaming SLM principles in overall land use planning and development, enhancing knowledge and awareness, protecting habitat of globally important species, maintain hydrological cycles, mitigating effects of greenhouse gases, and reducing poverty. The project will be implemented in two phases, with the first phase focused on creating an enabling environment for SLM and piloting innovations (in progress since 2005), and the second phase drawing on lessons learned to deepen the policy and institutional commitment to SLM and completing demonstration projects that can later be scaled up and replicated.

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Chapter 13
Uzbekistan: Rehabilitation of Desert Rangelands Affected by Salinity, to Improve Food Security, Combat Desertification and Maintain the Natural Resource Base

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Synopsis The chapter describes briefly the two key land degradation problems faced by Uzbekistan (i) widespread loss of rangeland productivity and stability, including loss of biodiversity and invasion by unpalatable and/or invasive species and (ii) problems associated with rising saline water tables and land abandonment.

Results of research on vegetation distribution along salinity gradients, and evaluation of some indicators of salt tolerance are reported. The outcome of the screening of many plant species, herbs, shrubs and trees and the development of agro-silvi pastoral systems as a means of rehabilitating degraded land and improving

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livelihoods is outlined. The development and adoption of Biosaline Agriculture practices as a way to restore productivity of salt affected desert lands is explained.

Key Points

- Rangeland vegetation of the arid and semi arid zones of Uzbekistan served as a crucial natural resource for livelihood development of the pastoral communities for many centuries and at the same time acts now as an “ecological tool” of protection against desertification. It is thus of great importance to preserve natural rangelands and to maintain their long term stability through application of consistent grazing management or using of improvement methods through cultivation of native drought and salt tolerant species.
- Facing the challenges of food security, Central Asian countries are keen to improve utilization of rangelands. Unfortunately, most governments in the region have limited financial resources, inconsistent legal instruments, and weak capacity to regulate and monitor sustainable use of rangelands. Thus, a more holistic approach to the ecosystem processes is needed in order to reduce the feed gap and mitigate rangeland degradation and desertification.
- Spatial and temporal changes of natural rangelands vegetation in the arid area affected by salinity need to be understood in order to initiate different revegetation strategies. Halophytes are an underutilized plant resource. They grow well in association with a variety of arid/semi-arid rangeland species and often provide severe competition to perennial species, both in natural and improved pastures.
- Where rangeland degradation has occurred there is need for rehabilitation measures to be applied. Incorporating fodder halophytes into the agro-silvi pastoral system or domestication of wild halophytes species represents low cost strategies for rehabilitation of desert degraded rangelands and abandoned farmer lands affected both by soil and water salinity.
- Introduction and adaptation of native drought tolerant fodder desert species and halophytes have the potential to provide a way to improve the livelihood of farmer’s income at abandoned degraded marginal areas.
- A mixture of desert fodder species planted within the inter-spaces of salt-tolerant trees/shrubs plantations improves productivity of degraded rangelands affected by soil salinization. Application of such an approach solves the animal feed gaps in the lands degraded both by overgrazing and salinity, and leads to increased income for farmers. Agro-silvi-pastoral approaches for landscape planning and rehabilitation of saline soils represent a model of ecosystem function/services for agro-pastoral communities as adaptation measures to mitigate climate change impacts
- Dryland salinity and associated water quality are recognized to be among the most severe natural resource degradation problems in the marginal desert belt of Aral Sea Basin. Access to irrigation water in this region has drastically decreased in the last years, which caused additional obstacles to rangelands productivity and agricultural production. Replacement of deep-rooted, perennial

native vegetation with shallow-rooted, annual agricultural crops and halophytic pastures has resulted in increased recharge causing shallow saline water tables leading to dryland salinity and loss of plant diversity. This results in greater amounts of water entering a groundwater system, water table rise and the concentration of naturally occurring salts near the soil surface.
- The Integrated Biosaline Agriculture Program for sustainable use of marginal mineralized water and salt affected soils for food-feed crops and forage legumes assists in improving food security, alleviating poverty and enhancing ecosystem health in smallholder crop-livestock systems. Diversification of agro-ecosystems and development of new agricultural capacities could increase income source of rural poor and farmers which so far are often dependent on two major crops (e.g. cotton and wheat).

Keywords Halophytes • Biosaline agriculture • Saline soils • Poverty alleviation • Rural poor • Small-holder • Crop-livestock systems • Food security • Agro-silvi-pastoral systems • Revegetation strategies • Drought tolerant fodder • Xerophytes • Sand dunes • Salinity gradient • Geobotanical survey • Carbon isotope analysis • Spatial and temporal changes • Grazing impacts • Above and below ground biomass • Salt-tolerant species • Radial attenuation of stocking pressure • Piosphere • Aral sea

1 Introduction

The inland Irano-Touranian desert ecosystem (that encompasses Uzbekistan and its neighbors) is considered one of the most fragile under currently ongoing climate changes. It is characterized by reduced richness of species, especially trees and shrubs, and, thus, by low resistance to local extinctions. With an area of 447,000 km^2 (approximately the size of France), Uzbekistan stretches 1,425 km from west to east and 930 km from north to south (Fig. 13.1).

The physical environment of Uzbekistan is diverse, ranging from the flat, desert topography that comprises almost 80 % of the country's territory to mountain peaks in the east reaching about 4,500 m above sea level. The south-eastern portion of Uzbekistan is characterized by the foothills of the Tian Shan Mountains, which rise higher in neighboring Kyrgyzstan and Tajikistan and form a natural border between Central Asia and China. The vast Kyzyl Kum Desert, shared with southern Kazakhstan, dominates the northern lowland portion of Uzbekistan. The most fertile part of Uzbekistan, the Fergana Valley, is an area of about 21,440 km^2 directly east of the Kyzyl Kum and surrounded by mountain ranges to the north, south, and east. The western end of the valley is defined by the course of the Syrdariya river, which runs across the north-eastern sector of Uzbekistan from southern Kazakhstan into the Kyzyl Kum. Although the Fergana Valley receives just 100–300 mm of rainfall per year, only small patches of desert remain in the center and along ridges on the periphery of the valley. The remainder has been developed for irrigated cropland and horticulture.

Fig. 13.1 Bordering Turkmenistan to the southwest, Kazakhstan to the north, and Tajikistan and Kyrgyzstan to the south and east, Uzbekistan is not only one of the larger Central Asian states but also the only Central Asian state to border all of the other four former Soviet Republics. Uzbekistan also shares a short border with Afghanistan to the south

Water resources, which are unevenly distributed, are in short supply in most of Uzbekistan. The vast plains that occupy two-thirds of Uzbekistan's territory have little water, and there are few lakes. The two largest rivers feeding Uzbekistan are the Amu Darya and the Syrdariya, which originate in the mountains of Tajikistan and Kyrgyzstan, respectively. These rivers form the two main river basins of Central Asia; they are used primarily for irrigation, and several artificial canals have been built to expand the supply of arable land in the Fergana Valley, Mirzachuli steppe and Aral Sea Basin.

Around 255,000 km^2 or 57 % of the country are rangelands. They have traditionally been used as common grazing lands for livestock. About 78 % of the rangeland cover is desert and semidesert plains (Gintzburger et al. 2003). Most of the farming in Uzbekistan's desert rangeland regions is Karakul sheep husbandry, followed by goat, camel and horse husbandry. The total number of head is greater than ten million (Mahmudov 2006). More than 2.3 million people are entirely dependent on livestock production for food and economic security (Yusupov 2003). The natural *Artemisia*-ephemeral and ephemeroidal rangelands are the main grazing lands for sheep and goats, and have been throughout history. Ninety-five percent of their total diet comes directly from the grazing and the remaining is harvested by the farmers and local herders and used when no grazing is available. Anthropogenic impact, on top of abiotic disturbances, is thus a part of the disturbance regime this area has been exposed to through the ages. High localized anthropogenic impact often results in rapid land degradation and even desertification, hence altering the native vegetation cover of rangeland areas. The human footprint has increased with the ever-growing human population, as can be seen in the expansion of degraded rangelands in Uzbekistan.

Land degradation of desert and semidesert rangelands throughout the whole Central Asian region has reached an alarming level, calling for prompt action. It was estimated that out of more than 16.4 Mha, 73 % are affected by degradation (Nordblom et al. 1997). of various origins, including anthropogenic impact and climate fluctuation. The anthropogenic disturbances alone are estimated to affect 7.4 Mha (UNCCD 2006). Grazing induced rangeland degradation is common across large desert zones of Uzbekistan and causing major ecological transformations resulting in biodiversity loss and occurrence of nonequilibrial ecosystems (Gintzburger et al. 2003). Yusupov (2003) estimated that of all disturbances, overgrazing by livestock was the most serious, accounting ting for 44 % of the total degradation, followed by uprooting and cutting of vital shrubs for fuel (25 %). All other disturbances, including all abiotic disturbances such as drought and wind erosion, accounted for only one-third of the disturbances. The effect of grazing is often localized and is ubiquitous around watering points and settlements. Changes in vegetation cover and composition have led to the disappearance of many native fodder species. Gradual reduction in biomass, changes of, for example, species composition from palatable plants into unpalatable, increased trampling and soil compaction are frequently observed. At the present time the area of degraded desert rangelands continues to grow due to overgrazing. A typical impact covers a radius of 2–5 km around watering points, with the most intense degradation occurring closest to the wells. Grazing occurs throughout the year. The animals are kept half of the year in the mountains or other distant regions, but they are brought back to the settlements as winter approaches. It is during this winter grazing seasons that most of the degradation occurs, as grazing pressure is high due to low vegetative production.

According to Salmanov (1996), the area of rangeland occupied by exotic/unpalatable plant species is now 1.5 million hectares (Mha). The original vegetation was completely removed because of the heavy grazing pressure. Mostly of anthropogenic origin (Ashurmetov et al. 1998). The degradation process has become severe and needs urgent measures to avoid the loss of phytogenetic resources and botanic diversity of the rangelands.

An understanding of the degradation processes currently ongoing in Uzbekistan rangelands is limited as traditional research has mostly focused on optimizing livestock fodder production (e.g. Shamsutdinov 1975). Since livestock production in Uzbekistan in arid and semi-arid zones is based on rangeland vegetation, current studies have focused on improvement of low productive grazing lands and rehabilitation of degraded rangelands. Less interest has been given to the driving factors of land degradation and their interaction with other ecosystem components e.g. response of vegetation to organizational changes, institutional transition from former Soviet system, and grazing induced disturbances. In recent years, due to poor localized grazing management, rangeland degradation has increased. An understanding of the current trend of vegetation changes due to ecological and anthropogenic factors gives the potential of sustainable management of natural rangelands. Driving factors of grazing induced rangeland degradation and their interaction with other ecosystem components were not often studied in previous works. Such a multidisciplinary approach of vegetation assessment was applied in semi desert vegetation of Karnabchul (see Fig. 13.3) where grazing induced rangeland degradation is common as observed in other desert areas of Uzbekistan (Rajabov 2010).

The effect of grazing is often localized and is ubiquitous around watering points and settlements in Uzbekistan. The grazing pressure diminishes with distance from these foci and forms a gradual change in vegetative cover, species composition and soil properties. To study such systematic changes, grazing gradient method has been widely used to examine the plant responses to grazing in different ecological zones (e.g. Austin 1977; Andrew 1988; Li et al. 2008). Grazing gradient analysis provides the ideal method by which to detect plant traits to a certain range of grazing pressures (Andrew 1988).

Interdisciplinary research based on an ecological approach was applied to detect the fine scale degradation processes and to understand full scenarios of plant-soil-animal interactions in order to keep the rangeland ecosystems in balance. This approach is the focus of this chapter and is illustrated by our field work in Uzbekistan.

2 Description of the Study Sites

The studies on desert vegetation along a salinity gradient were conducted in Kanimekh district at the Research Station of the Uzbek Research Institute of Karakul Sheep Breeding and Desert Ecology (lat. 41° N and Long 60° E at an altitude of 113 m). This region has a typical inland arid climate with a hot, dry summers and cold winters: annual mean temperature is 11.4 °C, and annual mean precipitation is 120 mm, which falls in the growing season from May to September.

We have chosen Kyzylkesek site – an area located between two hot springs (vertical drainage flow) in Central Kyzylkum Desert in order to determine spatial changes of vegetation as from the xerophytes in sandy dunes towards typical halophytes in Karakata salt depression (Fig. 13.2). Each zone differs by its relief, total soluble salts, floristic composition and botanic diversity.

Additionally we have conducted field research to assess the spatial and temporal vegetation succession of Karnabchul (a typical sagebrush-annuals semidesert rangeland) as a function of piospheric effects in two different range sites (39°50′N and 65°55′E) shown in Fig. 13.3.

2.1 Methodology

2.1.1 Vegetation Surveys

Geobotanical descriptions were done using 2 m × 50 m transect (in semi shrub plant communities) and 5 m × 50 m transect (in shrub plant communities – *Haloxylon*

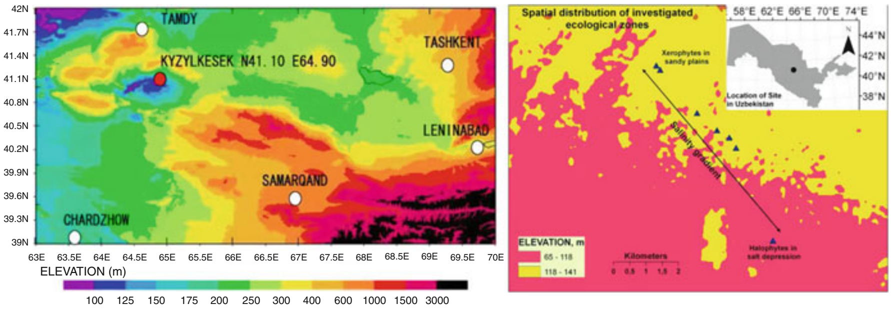

Fig. 13.2 (**a**, **b**) Topographical landscape map of target research area in Kyzylkum desert (Karakata saline depression) The *dot in the square* in the large scale map (*right*) indicates the location in relation to the whole region. The salinity gradient on micro relief level includes the area between two artesian thermal springs (shown as *triangles*). The plant community and soil was studied along this gradient (Source: Toderich et al. 2008)

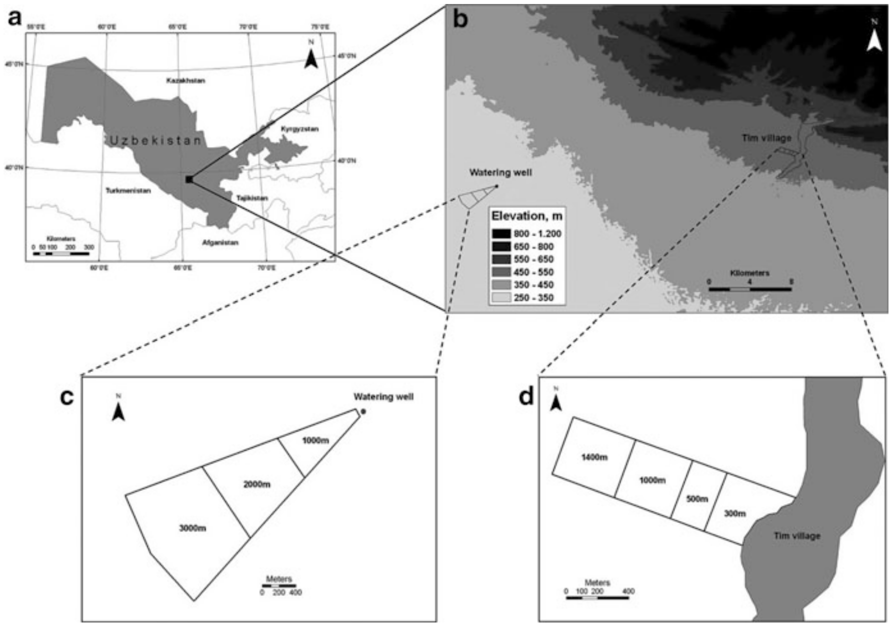

Fig. 13.3 Location of the study area in Karnabchul, Uzbekistan (**a**), digital elevation model (*DEM*) (**b**), schematic illustration of the measurement transects laid out perpendicular to the well (**c**), and village (**d**). DEM was obtained from Earth Remote Sensing Data Analysis Center (ERSDAC 2009; Rajabov 2011)

aphyllum Association), in three replications. Total numbers of shrubs of each species within the 100 and 250 m^2 were counted in three size classes (big, medium, small) based on plant height and diameter. For each size class and each species one representative plant was harvested and separated into woody, green and dead parts.

The total biomass for each subplot was determined by combining density data of each species present. Cover of individual shrub species was determined from a 50 m-line intercept along one edge of the 2 m $\times$ 50 m and 5 m $\times$ 50 m plot.

Aboveground biomass of investigated species was harvested at the end of October each year. Seasonal measurements of vegetation parameters (biomass, density, vegetative cover) along the apparent grazing gradient were conducted during 2005–2007. A conceptual framework of successive vegetation changes along the grazing gradient was developed by applying State and Transition (S&T) models. Vegetation data were analyzed by applying Non Metric Multidimensional Scaling (NMS) ordination. Seasonal dynamics of the Normalized Difference Vegetation Index (NDVI) derived from Landsat imagery were examined to detect the vegetation changes caused by grazing. The vegetation succession was demonstrated as a presence/absence of unpalatable/palatable species in plant composition as a function of piosphere effects.

2.1.2 Soil Sampling

Soil samples were collected from different depths (0–20; 21–40; 41–60; 61–90; 91–120 cm). Sodium (Na^+) ion concentration was analyzed by water extract from air-dry soil and plant samples (100 mg of sample) and detected on atomic adsorption spectrophotometer (Hitachi 2007, Japan). Salinity gradient was characterized by contents of Na^+ ions in the soil profiles. The regression analysis was applied to investigate correlation between remote sensing data, Na^+ ion content and EC values calculated from field data in order to predict soil salinity and vegetation changes.

Soil Salinity was also determined using an electromagnetic conductivity device (EM38) was standardized at reference temperature of 25 °C as EC increases at a rate of approximately 1.9 % (Rhoades et al. 1999). We used the formula provided in Sheets and Hendricks (1995), who fit the curve to a conversion table given in USDA (1954): $EC_{25} = EC_a * [0.4470 + 1.4034\varepsilon^{(T/26.815)}]$, where EC_{25} is standardized EC_a and T-soil temperature.

2.1.3 Carbon Isotope Analysis of Desert Vegetation

The distribution and abundance of desert plant communities were examined. Plant species were collected along a sequence of increasing ground-water depths in eight transects. Experimental data from Carbon and Oxygen isotopes were used to assess the responses of native plants to salinity and the effect of salinization on natural vegetation in Uzbek dryland ecosystems.

Carbon isotope composition ($d^{13}C$) of plant material is related to intrinsic water use efficiency in C_3 plants (Farquhar et al. 1989). The positive correlation was found between the salinity and the $d^{13}C$ of leaf organic matter both in salt-tolerant species and salt-sensitive species (Seemann and Critchley 1985). These reports indicate that salt stress may decrease the CO_2 concentration inside the leaf via the stomata closure and consequently increase the intrinsic water-use efficiency (Naoko et al. Unpublished data). There was, however, no report that presented the response of the $d^{13}C$ of leaf organic matter to the salinity

Carbon and oxygen isotope ratios were expressed by the following equation:

$$\delta^{13}C \text{ or } \delta^{18}O = \left(\frac{R_{sam} - R_{std}}{R_{std}}\right) \times 1000\ (‰)$$

where R_{sam} and R_{std} represent the $^{13}C/^{12}C$ or $^{18}O/^{16}O$ of the samples and standard, respectively. PDB and VSMOW were used for the standards for $d^{13}C$ and $d^{18}O$, respectively.

The photosynthetic organ samples (leaves and short pieces of stems in the case of aphyllous species) were oven-dried at 70 °C for 48 h and finely ground. The $d^{13}C$ in the organic samples was analyzed using a continuous flow system of an elemental analyzer and an isotope ratio mass spectrometer (Flash 2000 and Delta S, Thermo Fisher Scientific) at Field Science Education and Research Center, Kyoto University, Japan.

3 Results and Grazing Management Implications

3.1 Spatio-Temporal Changes of Vegetation of Semi-desert Rangelands Along a Grazing Gradient

The long term effect of grazing on semi-desert rangeland vegetation was studied in proximity of a typical watering well located 25 km south-east of Zirabulak Mountains in Karnabchul. Vegetation parameters (projective cover, density, green biomass of perennials and above-, below ground biomass of annuals) were collected in a radius of 3,000 m from the watering point.

Vegetation cover of study site is strongly affected by livestock grazing. Radial attenuation of stocking and grazing pressure from the watering point (the so-called piosphere effect, Lange 1969) resulted in changes in perennial and annual species composition. Radial symmetry of grazing pressure is resulted in rapid changes of vegetation community. The spatial variability that was observed shows gradients, and is derived from intense grazing around water sources at the well site. Grazing-driven changes in perennial and annual species composition in the closest areas and intermediate distances from the focal point were demonstrated as presence/absence of unpalatable/palatable species in plant composition.

The prevailing vegetation stratum of the study area is dominated by semi shrub (*Artemisia diffusa*) and perennial/annual herbaceous species (e.g. *Carex pachystylis*, *Poa bulbosa*, *Bromus tectorum*, *Alyssum desertorum*, *Trigonella noeana*). Existing physiognomy and floristic pattern of Karnabchul represents homogeneous type of vegetation which is commonly described as *Artemisia*-ephemeral rangelands

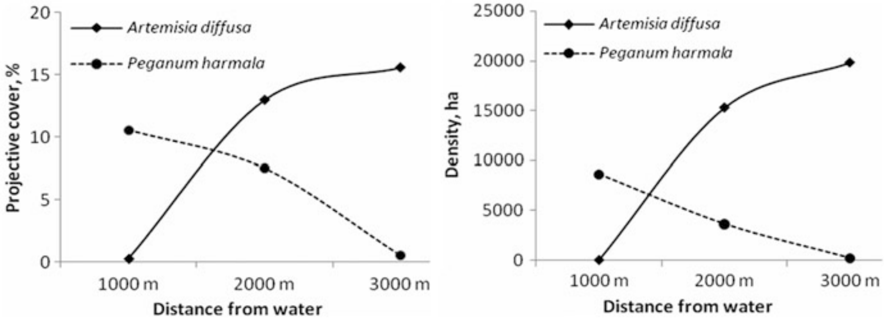

Fig. 13.4 Interrelation of typical fodder (*Artemisia diffusa*) and unpalatable species (*Peganum harmala*) along a grazing gradient from a fixed watering point in Karnabchul

(Gaevskaya 1971; Salmanov 1986). This type of rangelands is characterized by low forage productivity (0.15–0.36 t DM/ha^{-1}) with high interannual variations that is largely dependent on climatic conditions (Gaevskaya and Salmanov 1975). The vegetation of *Artemisia*-ephemeral rangelands is the main source of forage for livestock, and has been throughout history. Despite the low forage production of these rangelands, they provide 95 % of total diet of livestock. Anthropogenic impact is thus a part of the disturbance regime to which this area has been exposed since time immemorial.

Throughout the 40 years since the well was established, *A. diffusa* has been constantly overgrazed and trampled by livestock. Vegetation is usually absent around the well within the radius of 60–80 m. This zone is characterized by a highly compacted, flat surface with black or brown color as a result of intense trampling. At the next 1,000 m from the well invader plant *P. harmala* dominates. This plant is recognized as an indicator of overexploited-overgrazed rangelands and is not touched by livestock because of its toxicity, strong characteristic smell and high content of alkaloid in green leaves and seeds (Gintzburger et al. 2003). *P. harmala* thus dominates the first 1,000 m from the well (Fig. 13.4). A rise in the number of unpalatable plants in vegetation composition results in decreased qualitative values of the rangelands. Presence of *P. harmala* can be used as a sign of beginning of severe changes in vegetation structure under the intense grazing.

The shift towards dominance of unpalatable plants in vegetation composition has resulted in very low quality of grazing rangelands in term of fodder value of plants. As a function of increased distance away from the watering point, available grazing area for animals increases and stocking pressure on the this area decreases (Andrew and Lange 1986). This is reflected in the appearance of *A. diffusa* in the area of 2,000 m from the well (Fig. 13.4). Relatively high grazing pressure promotes *P. harmala* to remain in the vegetation cover consisting of 31 % of total vegetative cover and 18 % of the density in plant composition. In contrast, 56 % of the total perennial biomass of vegetation community in the distance of 2,000 m consists of *P. harmala*. Beyond 2,000 m, *A. diffusa* becomes more abundant and at a distance

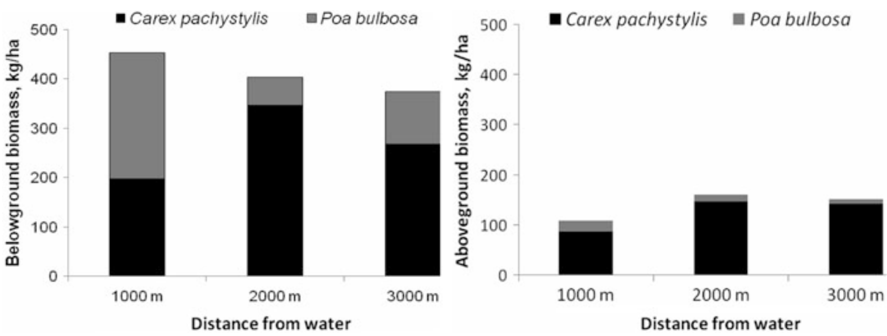

Fig. 13.5 Dynamics of below- and above-ground biomass of ephemeroids as a response to different grazing intensities

of 3,000 m it is dominant over *P. harmala*. Vegetation structure of ephemeral and ephemeroidal species is influenced by the heavy grazing. Competition existed between *P. bulbosa* and *C. pachystylis* under the heavy grazing pressure around the watering well. *P. bulbosa* had less aboveground biomass than *C. pachystylis* along all grazing gradients from the well (Fig. 13.5).

The greater abundance of *C. pachystylis* around the watering well is related to edaphic factor. Light sierozem soils near the watering well are a more suitable for *C. pachystylis*. As a piosphere response, the species had opposite directional changes along the grazing gradient – *C. pachystylis* increased with distance and *P. bulbosa* decreased with distance from the watering point (Fig. 13.5). However, despite of favorable soil condition for *C. pachystylis*, belowground biomass declined under the heavy grazing at the 1,000 m zone, where *P. bulbosa* dominates. An increase of ephemeroids under heavy grazing negatively affected persistence of *A. diffusa* and it was replaced by *P. harmala*.

The vegetation succession was demonstrated as a presence/absence of unpalatable/palatable species in plant composition as a function of piosphere effects. NMS analysis indicated the evident different processes of vegetation cover of two study sites due to distinct grazing regimes. NDVI analysis showed that Landsat imagery provides relevant information about vegetation changes along the grazing gradient in the Karnabchul semi-desert. Such results of multidisciplinary approach of vegetation assessment with combination of ecological models open the way in conception of realistic methods for sustainable rangeland management (Rajabov 2011).

Our studies confirm the identical trend of vegetation changes of previous studies along the grazing gradient. Grazing caused the appearance of intermediate herbaceous species in the vegetation composition of the village area. Increased grazing pressure shifted to the formation of another vegetation state with an abundance of intermediate plants. The density and other parameters of intermediate plants decreased as a function of distance away from the village. Trampling, however, has a more disturbing factor than grazing in the location closest to the watering well. In the last states of vegetation succession, some dominant ephemerals disappeared from the vegetation community because of high trampling by livestock animals, but not because of overgrazing. Besides trampling and grazing pressure, another important factor of vegetation change is over-supply of natural fertilizers and moisture (e.g. animal dung and urine) in topsoil around water wells due to high animal density and intensive utilization of water points. This, apparently, transforms soils around water sources into more mineralized conditions and consequently affects underground micro-flora and aboveground vegetation.

Increased grazing-driven disturbance has resulted in replacement of ephemeroids by undesired annuals. The radial symmetry of grazing pressure around the well has resulted in more rapid changes in vegetation structure than around the village where the grazing intensity is distributed around the elongated village area. Different edaphic factors played a key role in the formation of vegetation structure. Such vegetation changes of rangelands under the impact of grazing are distinctively described by integration of the S&T model. Piosphere analyses helped to identify states and transitions of vegetation communities and their shifts over time under grazing-induced disturbances. Application of such ecological concepts in range assessment helps to understand the driving factors of vegetation changes and to provide a framework for solution of degradation problems and sustainable management of natural resources.

3.2 Vegetation Changes Along a Salinity Gradient

Dryland salinity and associated water quality are recognized to be among most severe natural resource degradation problems in the marginal desert belt of Aral Sea Basin. The annual losses in Uzbekistan due to salinization have been estimated at US$ 31 million, while withdrawal of highly salt affected lands out of agricultural production costs an estimated US$ 12 million annually. Most of the irrigated lands in Aral Sea Basin are subjected to salinity due to sharp continental arid climate with aridity coefficient from 0.12 to 0.3. Initial sources of the accumulated salts in soil profiles are irrigation water. The risk of salinization is further increased due to the rising water table associated with poorly managed drainage systems.

Salt affected lands in desert areas of Uzbekistan demonstrate the most characteristic features of natural continental (not marine/coastal) salinization and alkalinization. Low organic matter (<1.0 %) and high accumulation of salts and poor water holding capacity render these soils unproductive. The predominant salinity type is sulfate-chloride. Sodium and magnesium are the dominating cations. Total nitrogen (N_2) and phosphorus (P) contents usually ranged between 0.7–5.5 and 10.0–18.26 mg/kg, respectively. Available potassium (K^+) content is classified as low or moderate. The dominant cation is Na^+ and the dominant anion is $SO_4{}^{2-}$.

Focusing on countrywide soil chemistry of surveyed salt –affected areas with shallow water table we found out that the predominant salinity type is chloride-sulphate, while sulfate -chloride type is also described. Ground water salinity varies from 2.0 to 8.2 g/l. Sodium and magnesium are the dominating cations. It was also found that the organic matter in these soils ranges from 0.7 to 1.5 g^{-1}, while the cation exchange capacity varies between 5 and 10 cmol(+) kg^{-1}. Total nitrogen (N) and phosphorus (P) contents in salt affected soils are low, usually ranging between 0.07–0.15 % and 0.10–0.18 %, respectively. Available potassium (K) content is classified as low or moderate. Consequently, the natural fertility of the saline soils, especially in the of main rivers deltas is characterized as rather low, and cultivation of most agricultural crops requires high inputs of chemical fertilizers or applying of costly leaching practice. This strategy, however, increases the risk of re-salinization in the root zone and leaching process has to be repeated every cropping season in order to avoid build-up of high salt concentration. In this respect the appropriate practices for salinity control should be selected based on the quantification of water and salt movement in the soil, crops response and adaptation to water and salinity stress and how environmental conditions and management influence these interactions. In this regard, efficient water use for irrigation coupled with introduction of modern bio-remediation technologies can help to integrate all interactions and define the best management for crop production under saline environments.

Access to irrigation water in this region has drastically decreased in the last years, which caused additional obstacles to rangelands productivity and agricultural production (Lamers et al. 2005; Toderich et al. 2010). Replacement of deep-rooted, perennial native vegetation with shallow-rooted, annual agricultural crops and halophytic pastures has resulted in increased recharge causing shallow saline water tables leading to dryland salinity and loss of plant diversity. This results in greater amounts of water entering a groundwater system, water table rise and the concentration of naturally occurring salts near the soil surface. Slight changes in temperature or soil moisture and dissolved salts regime could therefore substantially alter the composition, distribution and abundance of species. Increased frequency of climatic extremes and changes in soil salinity induce changes in plant functional group composition with invasion of non-native annual plant, which significantly reduce productivity in arid ecosystems. Therefore, functioning of these arid systems depends to a high degree on plant diversity.

4 Role of Biosaline Agriculture Technologies to Improve the Productivity of the Degraded Rangelands

4.1 Floristic Composition of Vegetation of Salt Affected Lands, Mineral Content and Evaluation of Halophytic Germplasm

The inland Irano-Touranian desert ecosystem including plant communities is considered one of the most fragile under currently ongoing climate changes. It is characterized by reduced richness of species, especially trees and shrubs, and, thus, by low resistance to local extinctions (see Chap. 17).

The vegetation cover of sandy deserts has a complicated spatial structure, which forms as a result of initial heterogeneity of the micro- and mesorelief landscape due to processes of soil denudation, salt accumulation and changing moisture content along soil profiles. Numerous seasonal surveys done by us during 2005–2011 have identified more than 380 species of different groups of salt loving plants (wild halophytes representing 19 taxonomical families). The study areas show a high endemism in plants (about 3.4 % from total species). Most noticeable is the relative richness of the Chenopodiaceae with nearly 33 %, equivalent only with Australia's chenopods. It is also quite rich in Asteraceae (20 %), Poaceae (11 %); Fabaceae and Brassicaceae (about 11 %). Species belonging to Polygonaceae, Plumbaginaceae, Zygophyllaceae, Cyperaceae account for a smaller share (3–5 %), whereas, Eleagnaceae, Plantagainaceae and Frankeniaceae make up an even smaller part (<1.0 %) of rangelands halophytic pastures. Among cited plant resources there is a number of native and exotic halophytes both C_3 and C_4 plants suitable for reclamation of arid and semi-arid, salt/affected and waterlogging areas that have proven very useful in demonstration trials.

The distribution of halophytic vegetation is related to inter-specific and intra-specific plant species competition, grazing capacity and land management. Desert topographical features and salinity gradient are of primary importance in determining the contribution of species with different photosynthetic pathways or taxonomic relations in forming of core ecological plant community types or vegetation units. Relative abundance of different growth forms and different pathways vary with seasonality of precipitations; e.g. spring-summer rainfall favors the abundance of C4 pathways chenopods. Annual ephemerals (short-lived) and ephemeroids occur in spring-early summer in times of moisture availability both in open rangelands areas and/or beneath the canopy of perennial plants. Our observations show that as results of drought impact the prevalence of open areas on rangelands increases with aridity and many species become increasingly restricted to run-on or moisture accumulation places. In high saline areas (named solonchaks) there is virtually no plant cover or only limited number of salt loving (halophytes) can grow.

Based on this mapped vegetation pattern distribution (Fig. 13.6) and on ground data we found that there were only a few core species, which determine productivity of rangelands of the studied biotopes/niches. Assessing the grazing potential of degraded rangelands by mapping zonal halophytic vegetation allowed us to identify salt pioneer plant species for each studied zone in order to initiate the reclamation process of saline prone soils. Among frequently found species there were *Climacoptera lanata*, *Kochia scoparia*, *Atriplex nitens*, *Salsola rigida*, *Halothamnus subaphylla* (Chenopodiaceae), *Glyzhyrrhyza glabra* (*Fabaceae*) annual and perennial species, growing well both on salty crusts (solonchak-alkaline soils), on clay and gypsum deserts, on takyr and high saline sandy soils . Therefore, we consider these species as a model plant for calculation of rangeland productivity both on virgin area and under cultivation (agro-silvi pastoral model) by using supplement irrigation with low quality water and application of fertilizers (Toderich et al. 2008).

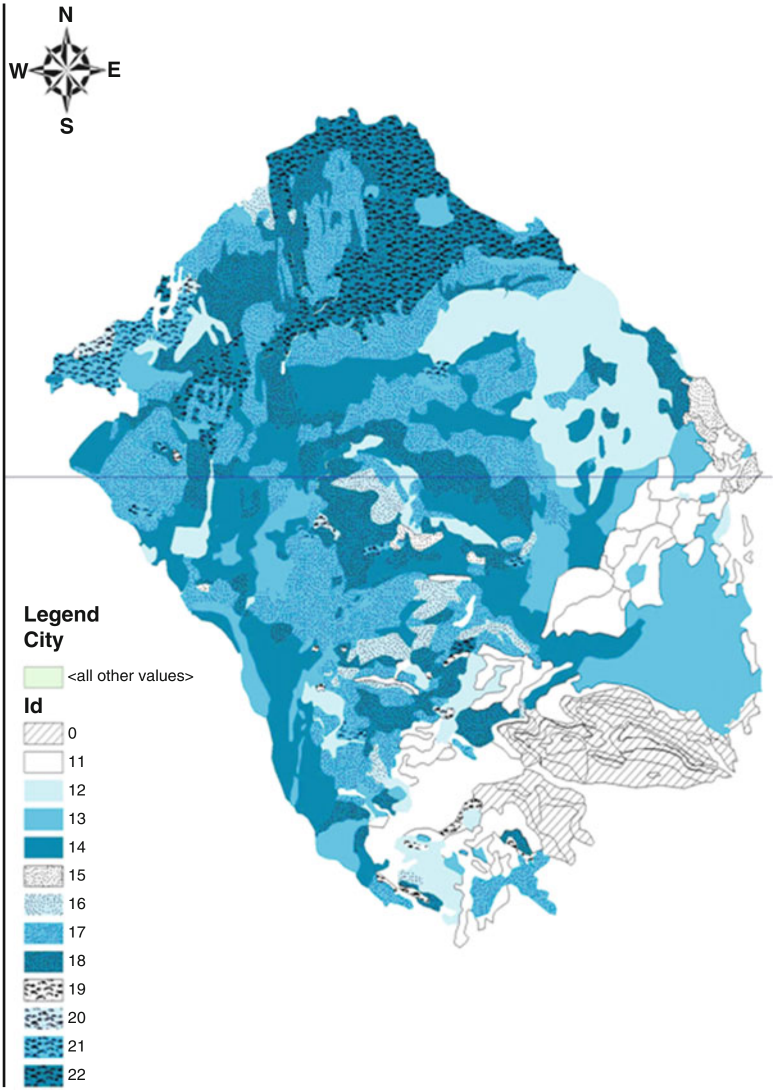

Fig. 13.6 Mapping of dominating (edificators) plant C4 species on the territories of Kyzylkum desert along a gradient of salinity (1–4 soils of low salinity; 5–8 medium salinity; 9–12 high salinity)

Plant composition, soil salinity, water table level and pasture yield were quantified in five main ecological zones. The dominating life forms are halophytes (chamaephytes) in sites of high salinity, and xerophytes (therophytes) in sites of low salinity. Spatial and temporal variations in the standing crop biomass were pronounced. The accumulation of green biomass started during spring and reached a maximum in autumn, when photosynthetic activity was maintained to account for transpiration losses. There was a general trend of increasing salinity and concentration of different ions along the salinity gradient. The periodical variation in the water table was insignificant, while a significant drop in salinity and the concentration of different ions was detected in spring, which was attributed to the diluting effect of rain water during that season. Analysis of cover vegetation of each visually divided zone along a micro-scale level has assisted to determine the dominant species in each zone, identified based on the total soluble salts in the soils. In the first zone (named as wet solonchaks), where there was a high mineral content, species of genus *Salicornia*, *Aeluropus*, *Suaeda*, *Halostachys*, *Halimocnemis*, *Climacoptera* were widely distributed. The vegetative period of all these species begins fairly late because the marshes are under water for a long part of the year.

4.2 Plant Density of C_3- and C_4 Species in Relation to Na and K Accumulation and Biomass Productivity

The highest density of xeropsammophyte and xerohalophyte plant communities belongs to C_3 species consisting of 89–94 % and 74–91 %, respectively (Fig. 13.7). The ratio of C_4 plants showed smaller values than C_3 plants for both plant communities. As its name implies, the plant density of haloxerophyte community represented considerably rapid changes during the seasons in term of the ratio of C_3 and C_4 plants. In spite of the dominancy of C_3 species in haloxerophyte community, the proportion of C_4 species noticeably increased compared with other plant communities. The contribution of C_4 species showed 19, 70 and 45 % during spring, summer and autumn seasons, respectively. However, during the summer season relatively increased values of C_4 species is observed for all plant communities.

Data collected during many field expeditions throughout Kyzylkum desert and Priaralie including plateau Ustyurt show clearly that there are changes between perennial and annual rangelands species ratio along salinity and soil moisture gradients. As is seen from Fig. 13.7 the biggest numbers of perennials occurs within semi shrub plant community on non saline soils. With increasing of soil salinity on typical halophytic plant community on solonchaks desert depression in botanic diversity the perennials is decreasing up to 50 %, while percent of annual species out of total plant diversity is sharply increased along salinity gradient.

Results showed that ratio of C_3 and C_4 plants in vegetation communities differ both along the salinity gradient and on seasons of the year. C_3 species such as *A. Lehmannii*, *A. diffusa*, *A. pseudoalhagi*, which occurred mostly on 1–3 ecological zones and some of tree species accumulate insignificant amount of sodium in leaves (0.63–7.34 g kg^{-1} of dry matter). Considerably high content of sodium (about ten times higher) was found in the leaves of *P. harmala* (52.33 g kg^{-1}) which is one of the plant components of haloxerophyte vegetation association. Such C_4 species

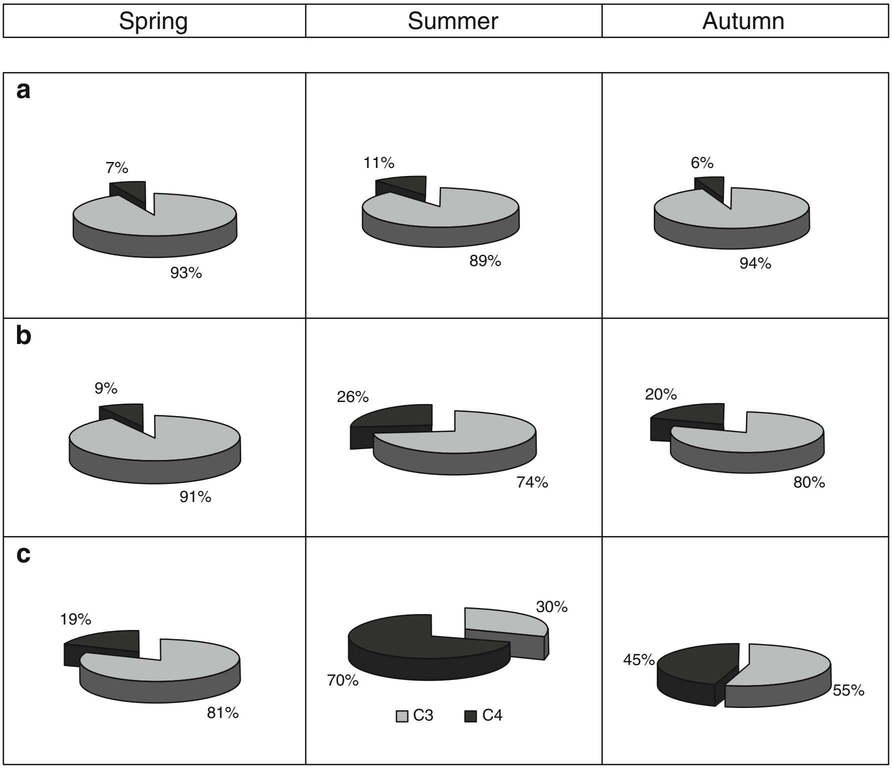

Fig. 13.7 Ratio of species with C_3 and C_4 types of photosynthesis in different plant associations (**a** – xerophytes, **b** – xerohalophytes, **c** – haloxerophytes) during vegetation season

as *H. aphyllum*, *S. paulsenii*, *H. hispida* accumulate 20–90 g kg^{-1} of sodium in green above ground parts. The representatives of C_4 species (*C. lanata*, *Sueda* sp.) of haloxerophyte plant association are capable to accumulate up to 300 g kg^{-1} of sodium. Proportion of species with C_3 and C_4 type of photosynthesis at the three plant communities considerably differentiated along the spatial and temporal scales (Fig. 13.8a, b). The highest density of xerophyte and xerohalophyte plant communities belongs to C_3 species consisting of 89–94 % and 74–91 %, respectively. The ratio of C_4 plants showed smaller values than C_3 plants for both plant communities. These plant resources have not yet been widely used as part of the arid production system of Uzbekistan by the pastoralists and farmers. Previous studies have shown that many wild halophytes grow well in association with a variety of salt tolerant traditional crops and often provide severe competition to tree/shrubs species, both in natural and improved pastures both on saline and disturbed mine sites (Toderich et al. 2007, 2008).

Investigations in 2011 identified that the ratio of C_3 and C_4 plants in vegetation communities differs both along the salinity gradient and on seasons of the year.

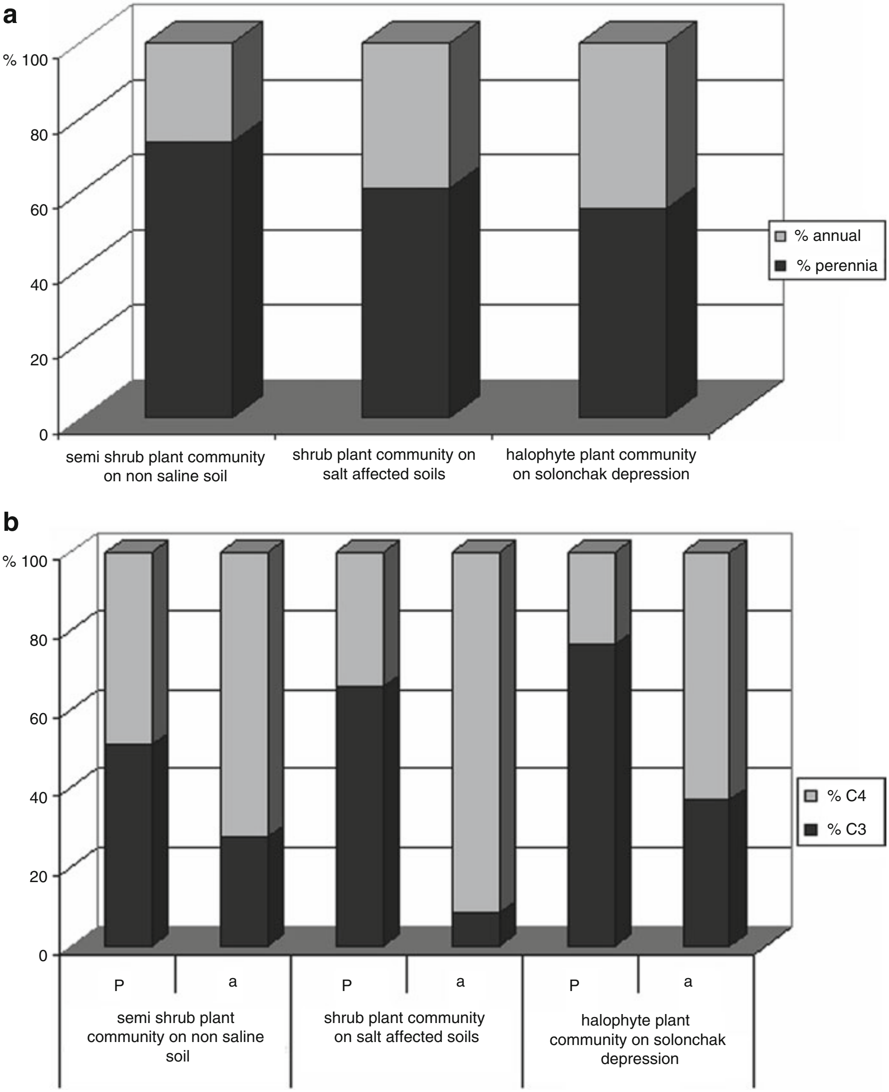

Fig. 13.8 Ratio of perennials and annuals among desert rangelands plant associations along salinity gradient. (**a**) is displayed according to location in landscape and (**b**) is displayed according to photosynthetic pathway (C_3 or C_4)

Along the salinity gradient the ratio of C_3:C_4 species (averaged over all seasons) is represented as 10:1, 10:2 and 10:9 for xero-, xerohalo-, haloxerophyte plant communities, respectively. Regular prevalence of C_3 species is observed, as proportion of C_4 species in the flora of desert vegetation of Uzbekistan does not exceed than 4 % (Pyankov et al. 2001; Toderich et al. 2007). Nevertheless, proportion of C_4 species is increased along the salinity gradient and in haloxerophyte plant

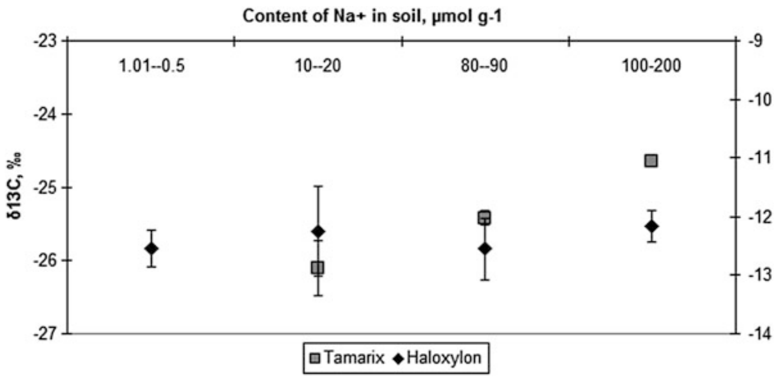

Fig. 13.9 Leaf carbon isotope ratio of C_3 (*T. hispida*) and C_4 (*H. aphyllum*) species along salinity gradient

community its amount becomes comparable to the proportion of C_3 species. C_4 species are mostly due to the salt affected soils and Na^+ is essential for C_4 species (for the translocation of pyruvate across the chloroplast envelope) where it functions as a micronutrient and to some extent all Chenopodiaceae species (studied C_4 chenopods) are halophytes (Akhani et al. 1997; Toderich et al. 2007). Although in the case of vegetation cover of Karakum desert (Pyankov et al. 2002) and grasslands of Argentina (Feldman et al. 2008) the increased amount of C_4 species compared to C_3 species has been shown along the gradient of deterioration of soil condition and soil salinization. Significant dependence of C_3 species on soil salinization indicates a reduction of carbon isotope discrimination ($\delta^{13}C$ value) of studied C_3 species along the salinity gradient (from -27.39 to -24.79 ‰) (Fig. 13.9). A 2 ‰ differences in $\delta^{13}C$ value of C_3 plants indicates a difference in water-use efficiency of about 30 % (Ehleringer and Cooper 1988; Ehleringer et al. 1998; Dawson 1993). In this case, C_4 species demonstrates independence of $\delta^{13}C$ value along the salinity gradient (Fig. 13.9).

A positive correlation of total productivity of main plant communities along the gradient of salinity with vegetative cover of C_4 species, especially due to the perennial C_4 tree and shrubs like *Haloxylon aphyllum* and *Calligonum leocacladum* was identified. The dominance of C_3 species in spring and early summer seasons in the studied areas is determined by abundance of short-live species of ephemerals and ephemeroids. The high ratio of C_4 species in summer comes from annuals halophytes from genus *Salsola*, *Climacoptera*, *Suaeda* etc. (more than 40 % among total C_4 species of haloxerophytic plant community). Species with C_4 type of photosynthesis with high transpiration efficiency are better adapted to soil water deficit or physiological drought that is strongly expressed in summer period, thus, the productivity of C_4 species within different desert plant communities are not very dependent on the regime of rainfall.

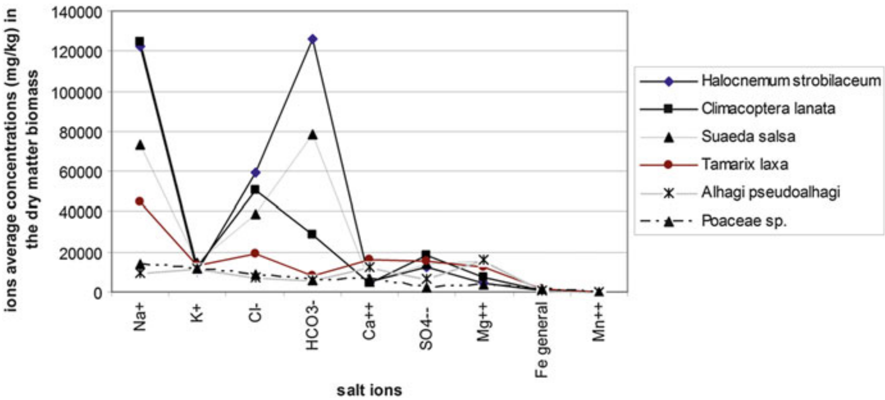

Fig. 13.10 Ion average concentrations detected in the aboveground biomass of salt tolerant rangelands species at the flowering stage

5 Mineral Composition of Forage as a Nutrition Source for Livestock

Our investigation on chemical composition of desert plants for ions like Cl^-, SO_4^{2-}, HCO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, as well as phosphorus and iron, showed significant changes within different halophytic forage species. As is shown on Fig. 13.8 the naturally growing plants, e.g., *Halocnemum strobilaceum*, *Tamarix hispida*, *Climacoptera*, *Halothamnus subaphylla* contains higher Na^+ concentrations near the critical limit for livestock, while legumes (*Alhagi pseudoalhagi*) and some gramineous fodder grass mostly accumulate K^+.

Based on upon a large amount of experimental evidence accumulated over years of research (some of which we shared above) we are now able to elaborate proven practices for range improvement operations/establishment and regeneration techniques. Depending upon the particular landscape and environmental conditions about 42 rangelands fodder species proved to be of most value for range introduction and eventually forage crop cultivation and seed multiplication and production. Among them *perennial Salsolas*, *Ephedra strobilaceae*, *Haloxylon aphyllum*, *Halothamnus subaphylla Campharosma lessingii*, *Kochia scoparia*, *Zygophyllum species*, *Alhagi pseudoalhagi*, *Glycyrrhiza glabra*, *Lycium turcomanicum*, *Lycium ruthenicum*, some *Calligonum* species, *Ceratoides Ewersmannia*, *Camphorosma Lessingii*, *Kochia prostrata*, *K. scoparia*, *Limonium gmelinii*, *Salsola arbuscula*, *Psylliostachys suvorovii*, annual *Salsola* spp., *Atriplex* spp., *Bassia hyssopifolia*, *Halocnemis varia*, and others showed promising results in increasing productivity of degraded rangelands.

Fig. 13.11 (**a**) Natural pastures at Kyzylkesek site highly affected by salinity (before improvement); (**b**) rehabilitation of saline prone lands by using *Atriplex nitens* (monotypic cultivated halophytic pasture after improvement)

The main rangelands restoration techniques include:

- Establishment of artificial phytocenoesis (single and mixed species stands) by direct seeding of salt tolerant crops and halophytes for controlling water table and salt balance on abandoned non-productive pastures;
- Introduction of a range of deep rooted annuals and perennials forage species, legumes, chenopod and tree species for increasing of arid fodder production;
- Tree plantations, shelterbelts and wind breaks.

The rangelands grazing capacity and yield of green/dry biomass significantly increase, when agro-silvi pastoral management practices are applied. An integrated, landscape approach, in which both agricultural land uses and conserved forest areas are closely integrated in a mosaic landscape, can provide an important means of conserving biodiversity within agricultural landscapes, while also maintaining farm productivity. Agricultural mosaics which retain abundant tree cover (whether as forest fragments, riparian areas, live fences or dispersed trees) can conserve high plant and animal species richness, by providing complementary habitats, resources and landscape connectivity for a significant portion of the original biota. Landscape configurations that connect dryland saxaul (*Haloxylon* spp.) and other trees forest patches and retain high structural and floristic complexity will generally conserve more species than those lacking connectivity or habitat complexity.

The areas near subsoil wells (hot springs) and wet solonchaks with predominance of halophyte plant community and low botanic diversity are considered the domains with the most rapid increase of pasture degradation (Fig. 13.11a, b).

For the reclamation of these saline prone rangelands we recommended the sowing of forage halophytes from genus *Atriplex*, *Kochia*, *Climacoptera* in pure stands as monotypic halophytic pastures or mixed as a multi-component halophytic pastures designated to be grazed in fall-winter season after rains, when surplus of salts will be washed out (natural effect of soil leaching).

Mixture of C_3/C_4 desert fodder species planted within the inter-spaces of salt-tolerant trees/shrubs plantations improves productivity of degraded rangelands affected by soil salinization. Application of such approaches solves the animal feed gaps in the lands degraded both by overgrazing and salinity, and promotes increased income for farmers. Agro-silvi-pastoral trials used for rehabilitation of saline soils represent a model for preservation and/or restoration of ecosystem function/services for agropastoral communities as part of their adaptation measures to climate change. The coexistence of C_3 and C_4 species is facilitated because C_3 species can colonize nutrient rich microsites, while C_4 species can occupy nutrient poor microsites.

Comparing different species within a small scale habitat along a salinity gradient we found that short-lived annuals or herbaceous species had significantly lower values of forage biomass than perennial species. The selection for trees with low $\delta^{13}C$ and, therefore, high transpiration efficiency, has the potential to increase total tree biomass growth in water-limited arid saline environments. Results obtained in this study showed that the successful performance of dryland afforestation technique is based on partial overlapping of natural niches of C_3/C_4 species. Therefore the optimal rehabilitation technique of saline prone rangelands consists from 12 % of tree cover, 20 % wild xerohalophytes, 38 % of biennual and 30 % annual forage crops, which in mixed planting significantly increase the productivity of rangelands. They prevent the accumulation of salts in the root zone. Results of this research indicate the suitable co-existence of C_3 and C_4 species is facilitated because C_3 species can colonize nutrient rich microsites, while C_4 species can occupy nutrient poor microsites.

There are a number of both C_3 and C_4 plants suitable for reclamation of salt/affected and waterlogged drylands that have proven very useful in demonstration trials. They provide potential to re-use areas that have been abandoned by agro-pastoralists and which are not used as part of the arid fodder production system.

Incorporation of fodder halophytes into the agro-silvo pastoral system or domestication of wild halophytes species represents low cost strategies for rehabilitation of desert degraded rangelands and abandoned farmer lands affected both by soil and water salinity. Late summer and early autumn time should be considered as the optimal period for transplanting of all the above mentioned non conventional halophyte species. Introduction of strip-alley livestock-farming system increased the productivity of rangelands by 2.0–2.5 times and slowed further degradation of rangelands. The proposed system (developed by the authors) of creation of agro-phytocenosis by mixture of natural halophytes with salt tolerant crops, fodder legumes and grass allow getting forage for animals almost all of the year. Salt tolerant crops cultivated into an agro-silvo-pastoral model benefits from the improvement of soils and microclimatic conditions provided by the shrubs. Considerable reductions were observed in wind speed, potential evapotranspiration, temperature and in the intensity of sand storms. First screening of wild halophytes for their gradual domestication should be done based on the following criteria: ash composition of forages; nutritional values and needs of farmers.

6 A Role for Biosaline Agriculture in Rehabilitation of Saline Land

Studies done by International Center for Biosaline Agriculture in Central Asia in collaboration with national partners from different institutions and agropastoral farms for the period 2006–2011 identified target areas of greatest potential for successful extensive pasture improvements, such as re-seeding of shrubs etc. Among them the most important fodder and biomass production value are: *H. aphyllum*, *Calligonum* spp., *Salsola paletzkiana*, *S. Richteri*, *S. orientalis*, *S. gemmascens*, *Artemisia* complex, *Halothamnus subaphylla*, *Kochia prostrata*, *Camphorosma lessingii*, *Eurotia ewersmannia*, *Alhagi pseudoalhagi*, *Astragalus* spp., *Glycyrrhiza* spp., *Carex* complex, *Poa bulbosa*, halophytic annuals and others.

The measures include the establishment of on-farm demonstration trials for using: (i) low quality water for irrigation and cultivation of suitable native wild and cultivated tree and shrub species, as well as use of winter/summer conventional and non-conventional drought and salt tolerant crops; (ii) domestication of economic-valuable native halophytes on un-productive salt affected abandoned by farmers lands and saline prone sandy desert rangelands; (iii) seed collection, post harvesting packages and marketing to create employment opportunities for a large number of people, particularly the poor rural, women and children in summer season; (iv) establishment of tree plantations and shelterbelts that provide bio-drainage input, organic matter, improvement of the microclimate, and promote by-products such as wood, fruit or fodder. Different rations of feeding of small ruminants were tested using traditional and non-traditional fodders. Studies have revealed sustainability and resource efficiency use of the integrated crop-livestock production system.

Planting of fodder halophytes on high saline lands integrated with salt tolerant trees and shrubs the importance of farming practice in mitigation of salinity and lowering of the GW table. On the high end of the gradient, soil salinity and sodicity (a measure of exchangeable sodium) were high in the *Climacoptera lanata* zone [(EC = 5.3 dS m^{-1}, sodium adsorption ratio-SAR = 44.0 (mmoles $L^{-1})^{0.5}$] and extreme in the *Tamarix hispida* zone [(EC = 21 dS m^{-1}, SAR = 274 (mmoles $L^{-1})^{0.5}$]. Endemic species produced maximum biomass in the zone where they originated, not in any other higher or lower vegetation zone. *Tamarix* species, *Haloxylon aphyllum* and annual halophytes, which were distributed across nearly all sites, had low frequency of occurrence. Based on this we have distinguished common growth forms into distinct groups corresponding to different ground-water levels. Three clearly defined groups of growth forms were strongly associated with three distinct ground-water zones, ranging from <3, 3–5 and >5 m, respectively. Four taxa groups were found to correspond to the three ground-water zones and to several other environmental factors that suggest a major botanical gradient exists relating to ground-water depth than to the secondary gradients like soil moisture, pH and to a lesser extent alkalinity and mineralization (Table 13.1).

The overall ranking of the trees, weighing all parameters concurrently shows that species of genus *Tamarix* and *Elaeagnus angustifolia* have the highest potential for

Table 13.1 Performance indicators of native and introduced of C_3/C_4 tree and shrubs species under saline conditions in Kyzul Kum

Species	Growth rate (at 1st years)	Root establishment	Reproduction	Above ground DM	Biodrainage; feed and fire-wood value	Soil salinity level	Winter frost tolerance	Rate survival (%)
Haloxylon aphyllum[a]	+	±	a.b.c	+	±	+	+	±
Tamarix hispida		+	Invasive	±	±	+	+	+
T. androsovii	±	+	Invasive	±		+	+	±
Populus alba	±	±	a.b	±		+	±	+
P. nigrav var. Pyramidalis	±	±	a.b	±	+	±	+	−
P. euphratica	±	±	a.b	±	+		±	−
Salix babylonica	±	±	a.b.c	±	±	+	±	−
Hyppophae ramnoides	±	±	a.b.c	±	±	+	±	+
Elaeagnus angustifolia	+	+	a.b.c	+	+	+	±	+
Robinia pseudoacacia	−	+	a.b.c	+	+	−	+	±
Morus alba	+	±	a.b	+	−	±	±	+
Morus nigra	+	±	a.b	+	±	±	±	±
Malus domestica	±	±	a.b	±	±	−	−	±
Malus silvestris	±	−	a.b	±	±	±	+	±
Cynodon oblonga	±	±	a.b	±	±	±	−	+
Armeniaca vulgare	±	±	a.b.c	±	±	±	−	+
Thuja occidentalis	−	−	B	−	−	−	±	−
Dyospyrus lotus	+	+	a.b.	+	+	+	±	−
Rosa canina L.								
Atriplex undulata[a]	+	+	a.b.c	−	+	+	+	+
Artemisia diffusa	+	+	a,b,c	+	−	−	+	+

+ high potential, ± medium potential, − low potential

[a]C_4 species, while others tested species belong to C_3

growing on both loamy and sandy soils, which represent the dominant soil textures in the region. As a result, at marginal sites where a shallow, slightly-to-moderately saline groundwater is available throughout the growing season, *Elaeagnus angustifolia*, *Robinia pseudoacacia* and newly introduced *Acacia ampliceps* showed the fastest growth and highest water use. This indicates the suitability for planting on low fertility saline lands. Preliminary outcomes of the study on salt-affected soils have also indicated that tree plantations with *E. angustifolia*, *Populus nigra var. pyramidalis*, *Morus* spp. have potential for increasing the soil organic matter due to the relatively rapid leaf litter decomposition. *Morus nigra* and *Cydonia oblonga* showed reasonable DM production on degraded land, with high biomass allocation towards the root fraction. Among tree species, Poplar (*Populus alba*, *P. nigra var. pyramidalis* and *P. euphratica*) showed maximum growth for all parameters studied followed by mulberry (*Morus nigra*). *Populus diversifoilia* which displayed high rates of leaf and wood production appeared to be the most sensitive to saline sandy-soil type. Similarly, it had slow longitudinal root growth and low root DM production at sandy site while exhibiting superior below-ground development at the sandy-loamy soils. Introduced coniferous species *Thuja occidentalis* was the only species that showed poor growth under furrow irrigation at the Dashauz province and at the second year died due to its high sensitivity to frosts

Evaluation of survival rate, performance and productivity including biomass and seed production of non-conventional tree/shrubby halophytes firstly introduced in Central Asian flora including: *Acacia ampliceps*, *Atriplex nummularia*, *A. undulata* and *A. amnicola* by International Center for Biosaline Agriculture showed its high potential for the reclamation of salt-affected marginal lands. All species tolerated average root-zone salinity of 8–16.8 dS m^{-1}. Seedlings of *Acacia ampliceps* were obtained from by direct seed sowing in the field (February 2006) and through the establishment in plastic bags. The growth rate was very fast @ 12–18 cm/month at the rooting stage and 25–30 cm/month, when the basal stems develop a woody character. Plant growth of *Acacia ampliceps* raised from direct seeding was much higher than with similar plants grown after transplanting by seedlings (from plastic bags). Among *Atriplex* spp. highest seed germination (approximately 89 %) under field condition was observed for *Atriplex undulata*, which showed a rapid growth rate and accumulation of biomass. Being grown at a high plant density of 10–12 plants m^{-2} (normal density of this shrub is 4 plants m^{-2}) in the first year, this species with its large canopy can occupy the inter-row spaces forming a dense mono-component halophytic pasture. The biomass produced in 1.5 years was 5.6 kg m^{-2} and was readily browsed by cattle and small ruminants. Biomass of *Atriplex undulata* at the Akdepe Experimental site increased with high density level of plant per square meter (5.0–5.8 thousand. plant/ha). Replacement of 30 % of individuals has been done in August 2006 in order to maintain the stand and decrease plant density. Low seed germination of about 55 % was observed in *Atriplex nummularia* and *A. amnicola* (only four shrubs of the latter plant survived). Comparative studies on seasonal plant performance, accumulation of green biomass in *Acacia ampliceps* and *A. nummularia*, *A. amnicola* and *A. undulata* was observed after transplantation into the open field.

Farmers, pastoralists and householders, especially women groups were trained and involved in the activities related to saline water and crop management practices, efficient forage bio-saline production, post-harvest by product marketing and results dissemination. Involvement of the farming and agro-pastoral communities in participatory decision-making, research approach, on-farm testing and verification, as well as faster dissemination of sustainable technologies to mange soil salinity, water table depth, irrigation and drainage water quality will lead to the understanding of salt movement as results of management practices.

The results of this study showed that spatial and temporal changes of natural rangelands vegetation in the arid area affected by salinity in order to initiate different revegetation strategies. Information about soil ion content, electrical conductivity, performance of indicator species, biomass clearly indicates which plant species are most likely to contribute to the reclamation process of saline soils. Plant species diversity and distribution is determined by local soil specificity, i.e. it's physical and chemical composition, micro-relief and soil moisture. The climate itself as has been noted by Shuyskaya et al. (2008) plays a secondary role.

We also found that halophytes as underutilized plant resources grow well in association with a variety of arid/semiarid rangeland species and often provide severe competition to perennial species, both in natural and improved pastures. Integrated Biosaline Agriculture Program for sustainable use of marginal mineralized water and salt affected soils for food-feed crops and forage legumes developed will assist to improve food security, alleviate poverty and enhance ecosystem health in smallholder crop-livestock systems. Such diversification of agro-ecosystems and development of new agricultural capacities could increase income source of rural poor and farmers which so far are often dependent on two major crops (e.g. cotton and wheat). Furthermore, the activities proposed here will also contribute to large scale biomass production, which will build up the soil organic matter. It will thus also contribute to make the poor farmers more resilient against climate change. The evaluation, domestication and large scale utilization of native and introduced halophytes and salt tolerant plant resources in sole or mixed farming system would have a significant impact on salinity control and remediation as well as on the economic development of arid/saline lands commonly observed in the whole Aral Sea Basin. Although, the cultivation of trees requires a waiting period, the use of multipurpose species, as investigated in this study, promises the farmers a return from those areas of their land where crops are no longer profitable. The expansion and commercialization of non-timber forest products has the potential to increase the cash income of rural Uzbek households.

An aspect that remains unstudied is the degree to which this type of afforestation effort can contribute, on a larger spatial scale, to carbon sequestration; however, methane emissions from unfertilized poplar plantations as well as natural Tugai vegetation are below the detection limit (Scheer et al. 2008). If carbon trading benefits can be added to the benefits from non-timber forest products, this would create a "win-win" situation from both an ecological and economic point of view (Gintzburger et al. 2005a, b, c; Khamzina et al. 2006).

Planting herbaceous fodder crops between fruit and fodder trees on intensive agro-forestry plantations leads to increase the productivity of land degraded by both overgrazing and salinity lands. Better plant growth, accumulation of green biomass and consequently yield of both fresh and dry matter were significant for alfalfa both in pure stand and in mixed artificial agro-phytocenosis including trees.

The biosaline agro-forestry concept evaluated in this study provides a means of on-farm drain water management, thus alleviating the need for expensive and potentially hazardous evaporation ponds. Moreover, it could create conditions for maintaining the investigated target remote desert and semi-desert areas as viable farming regions. Immediate actions to direct research towards reclamation of saline prone and desert lands, generation of useful non-timber products and achieving co-benefits of C sequestration by conserving natural resources, renewable energy sources, arresting waterlogging . One of the key motivations for government to develop and promote agroforestry is that it can generate these benefits in addition to financial benefits from the sale of commercial products. Further investigations should be done to show the significance of biosaline agroforestry to reduce poverty through improving household food and nutrition security.

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Chapter 14
Review of Efforts to Combat Desertification and Arrest and Reverse Land Degradation in Myanmar

N.N.O. Weine

Synopsis Myanmar is located in a region less vulnerable to desertification. Although there is no place which can be strictly defined as a sandy desert, some specific areas in the vast central zone of the country indicate the potential for land degradation due to the combined impacts of both the adverse climatic conditions and the stress resulted from human activities. This chapter gives a summary of the current situation of Myanmar in respect to desertification and land degradation

Key Points

- Land degradation in Myanmar is caused by water erosion, wind erosion, soil fertility depletion, salinization, alkalinization and water logging. Visible land degradation is recognizable in the central dry zone area of Myanmar and extends partially over the Divisions of Mandalay, Magway and Sagaing covering 17 % of the total area of the country. In these areas, soil erosion is intensive and rapid as a result of heavy rain showers and the low degree of rock compaction. Surface runoff has been estimated to be 30 %. Removal of the natural savanna vegetation quickly leads to erosion, which is most intensive at the start of the monsoon rains on bare soils. In the dry zone, where rainfall is already low, reduced infiltration means less effective utilization of precipitation. An increase of runoff also leads to the expansion of rill and gully erosion.
- The term "Dry Zone" is now being used to represent the dry central part of the country. As Myanmar is endeavoring to maintain its natural resources, the Ministry of Forestry strives to undertake the greening project throughout the country with the cooperation of all levels of the governmental sectors. The greening operation was started by planting trees in the 9 critical districts of the arid zone of central Myanmar and extended to 13 districts with the creation of new department namely the Dry Zone Greening Department (DZGD). This

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project also focuses on improving socioeconomic survival of rural people who live in the central arid zone and are badly affected by an acute shortage of fuelwood supply since the foremost fuelwood deficit areas are located in this dry zone. The Dry Zone Greening Department promoted utilization of wood fuel substitutes. The activities for the development of wood fuel substitutes include distribution of fuel-efficient stoves, promotion of fuel briquette production and utilization of agricultural residues.

- The primary causes of desertification and land degradation apart from low rainfall and more frequent and prolonged drought is the destruction of the catchments of natural water sources leading to water shortages in this dry zone. It has been estimated that approximately 8,000 villages are facing water shortage. So, the Irrigation Department and Water Resources Utilization Department under Ministry of Agriculture and Irrigation have been implementing drinking water supply and irrigation water supply program for food sufficiency and promotion of crop-productions in the dry zone. The Dry Zone is in danger due to the scanty rainfall, sparse vegetation and poor land use practices.
- Widespread deforestation and unplanned land use change can harm the landscape. Forestlands are vulnerable to encroachment due to expansion of human settlements and the intensity is directly- related to population of the expanded or newly located settlement. Ecosystem of wetland areas is expected to have a significant change due to expansion of human settlement. Inlay Lake ecosystem in the eastern part of the country is a significant example that shows water pollution and sedimentation in the water body is due to human settlement in uplands of the lake. It is rational that biological diversity in coastal areas would be adversely affected by the expansion of human settlement. These implications that would be experienced in any expansion of human settlement are given due consideration for minimizing the unintended consequences. Challenges facing integrated land management still remain and they include, among others, inadequate inputs, low capacity level of inter- and intra-agencies related with the utilization of land resources, the need for urgent economic returns and absence of comprehensive land use policy respected by all parties.
- The Ministry of Forestry, and the Ministry of Agriculture and Irrigation are the main agencies responsible to manage fragile ecosystems, combat desertification, including land degradation in all its forms, and mitigate drought. The Ministries concerned collaborate with the stakeholders at the local levels. to implement programs and projects such as the greening programs and integrated land development projects being carried out in the dry zone area of Myanmar which is the area most affected by drought. Due to very low rainfall and deforestation the majority of rural population in the area have been facing the problem of soil erosion and land degradation. In order to address the problems, reforestation and afforestation the governments are implementing programs, irrigation and water supply projects. Land degradation problems and the resulting rural poverty in the semi-arid regions in Myanmar are now being addressed by the governments through practicing sustainable agriculture and forestry management.

Keywords Dry Zone • Dry Zone Greening Department (DZGD) • 30-year Master Plan • Afforestation • Fuelwood • UNCCD • Fuel-efficient stoves • Water shortage • Drought • Irrigation soil erosion • Vegetables • Grains • Rice • Salinity • Ayeyawady Delta

1 Introduction

The Union of Myanmar is the largest country of South-East Asia. It is a tropical country located between latitudes 9° 28′N and 28° 29′N and longitudes 92° 10′E and 101° 10′E. The length from northern to southern tip of the country is about 2,060 km. The total land area of Myanmar is 676,577 km^2, of which about 51 % is covered by forests and about 27 % is arable (or potentially arable) land of 13 % is sown at any one time and 14 % is under fallow or is idle land. Existing farmlands are protected against changes to other uses so some land awaits development for cropping. Myanmar is regarded as an agriculture based country as it accounts for 40.2 % of the GDP and employs 64.1 % of the work force.

The country has several distinct climate zones ranging from the temperate region of the north to the Dry Zone in central Myanmar and the monsoonal belts in the northwest, west and south. It has a tropical climate with three seasons namely Rainy (mid-May to mid-October), Winter (mid-October to mid-February) and Summer (mid-February to mid-May). There is large variation in average precipitation as coastal areas receive average precipitation in the range of 4,000–5,600 mm while central dry zone receives precipitation in the range of 600 and 1,400 mm. During the wet season annual rainfall received by each region is quite different. In general, there is shortage of soil moisture in the dry zone even in the wet season, while excess moisture prevails in lower Myanmar. At the end of the wet (monsoon) season it is totally dry and most of the crops planted in the season need to rely on residual soil moisture, except those in irrigated tracts. In order to provide supplementary irrigation for monsoon crops and full irrigation for winter season sown crops, dams, weirs, reservoirs were constructed and pump stations were established so that enough food will be produced for the growing population.

2 Implications of Human Settlement Expansion on Farmland, Landscape, Forestland, Wetlands, and Biological Diversity in Coastal Areas

The government's policy objectives to boost agricultural production included development of land resources for agricultural expansion, provision of adequate irrigation water for agricultural purposes, support for agricultural mechanization accelerated transfer of improved new technologies and development and utilization of high yielding quality seeds. There is potential for this policy to impact on the nation's natural resource base.

- Farmlands: Existing farmlands are protected against changes to other uses. In the case of dam construction, existing settlements are to be shifted to new areas where new farm lands are to be developed.
- Landscape: Widespread deforestation and unplanned land use change can occur.
- Forestland: These are vulnerable to encroachment due to expansion of human settlements and the intensity is directly related to population of the expanded or newly located settlement.
- Wetlands: Ecosystem of wetland areas is expected to have a significant change due to expansion of human settlement. Inlay Lake ecosystem in the eastern part of the country is a significant example that shows water pollution and sedimentation in the water body due to human settlement in uplands of the lake.
- Biological Diversity in Coastal Areas: It is rational that biological diversity would be adversely affected by the expansion of human settlement.

These implications that would be experienced in any expansion of human settlement are given due consideration by government agencies so that the unintended consequences are minimized.

3 Myanmar's Dry Zone

The Dry Zone, which possesses one-third of both the population and area of Myanmar is vulnerable to the processes of land degradation and desertification.

According to the rainfall pattern, the Dry Zone has an area of about 67,700 km^2 or about 10 % of the country (Fig. 14.1). The Dry Zone comprises Lower Sagaing, Mandalay and Magway Divisions. There are altogether 13 districts and 57 townships in the Dry Zone. The Dry Zone suffers intense heat of monthly temperature ranging from minimum of 10 °C in the cool months to maximum of above 40 °C in dry months. The dry zone is surrounded on three sides by mountain ranges.

Towards the South it consists of undulating plateau with elevation of 150–200 m and a number of steep hilly chains rise above the plateau with peaks of hill reaching an altitude of 300–400 m. The arid and semi-arid zones are characterized by an extreme diversity such as soils, geomorphology, vegetation, water balance and human activities.

The annual rainfall in the central part of Myanmar known as the Dry Zone is less than 600 mm. The dry zone is prone to droughts. According to characteristics of drought using rainfall series, the worse drought that hit the area was during 1979 and 1980. The second worse drought that hit lower Sagaing and Mandalay (but not Magway) took place during 1982 and 1983. The third worse drought hit the whole area of the dry zone during 1993 and 1994.

The original vegetation of central Dry Zone is described as Savanna woodland which consisted of short deciduous trees and a ground flora composed of different

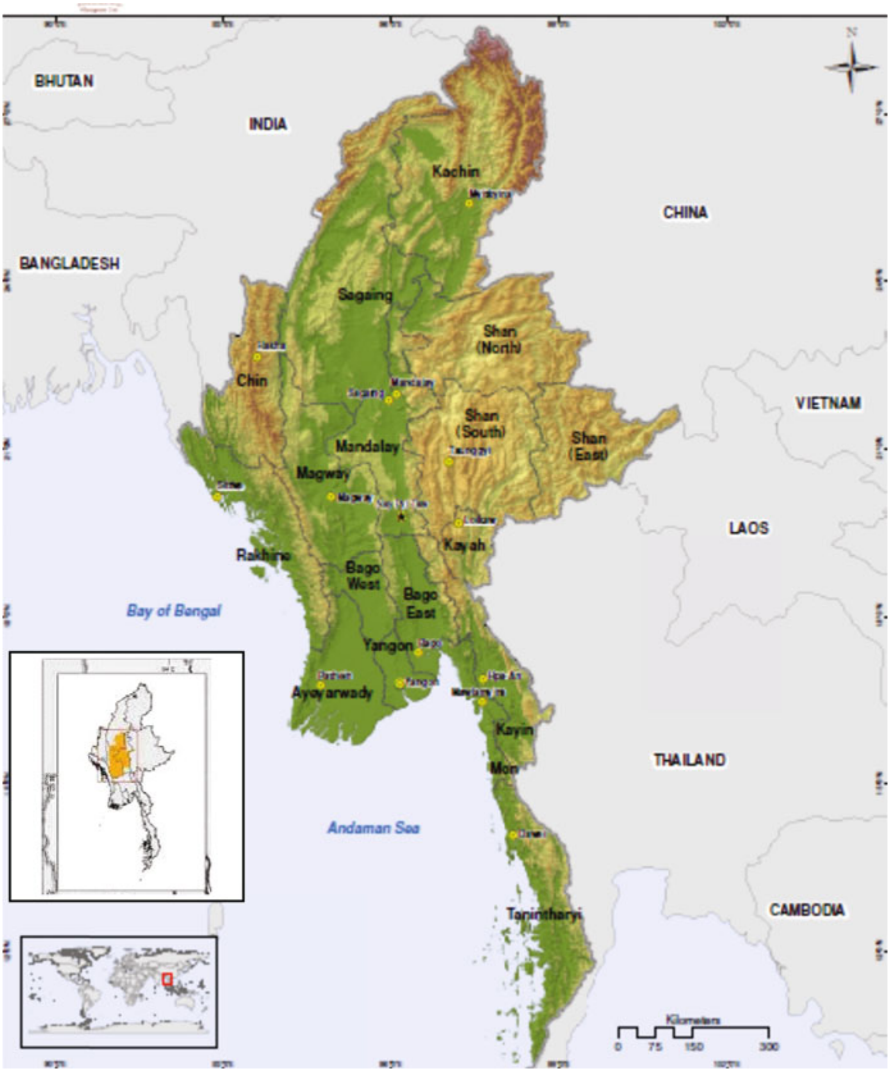

Fig. 14.1 Map of Myanmar, the 5th largest country in Asia showing the location and extent of the Dry Zone in central Myanmar (*inset*)

species of grass. Dry zone is the most important vegetable oil production region, which includes sesame and sunflower. Other important crops are rice, millet, cotton and tobacco. The major cash crops grown in the Dry Zone are cotton, sesame, pulses and beans. Seasonal vegetables such as onion, garlic, chillies, and tomatoes are also grown on some alluvial soils on the banks along the Ayeyarwady river. All suitable land is cultivated and there is hardly any scope for expansion. The farmers of this zone are mainly commercial, cultivating a variety of crops in a double cropping and rotational system. Intercropping is widely practiced in Chaung U, Sagaing and Kyaukpandaung, Mandalay while less in Magway. Poorer farmer families and laborers fulfill their incomes by cutting fuelwood or making *jaggery* both of which contributed to overexploitation of forest resources that tends to lead to deforestation.

4 Land Degradation/Desertification

The soils have eroded to varying degree and at some places they have been completely removed by water and wind erosion. The soil erosion is intensive and rapid as a result of heavy showers and a low degree of compaction of rocks. The surface runoff has been estimated to be 30 %. Removal of the natural savanna vegetation quickly leads to erosion, which is more intensive at the start of the monsoon rains on bare soils. Rates of soil erosion depend on the type and effectiveness of cover on the soil surface (Table 14.1). Some arid and semi-arid lands can support crops, but additional pressure from greater populations or decreased rainfall can lead to the loss of the present plants. Under these circumstances, the soil becomes exposed to wind, causing soil particles to be deposited elsewhere. A result of this is the erosion of the top layer of soil. The rate of evaporation increases due to the absence of shade and salts become drawn up to the surface. This leads to salinization and inhibits plant growth.

Wind erosion is a problem of arid and semi-arid regions with a dry season of more than 6 months. In such areas, natural vegetation is steppe-like with much bare soil. The fine particles of the soil such as clay, silt and organic matter are blown away by strong winds while coarse materials are left behind. The wind erosion starts at a wind speed of 25 km/h. Sand grains of 0.5–2 mm are rolled, fine sands of 0.1–0.5 mm are transported over few meters and finer particles such as clay, silt and organic matter go into suspension in the air. In Magway, dust cloud or ‘Red sky’ during March and April is due to this suspension.

About 11 % of the total land area is affected by wind erosion, which occurs mainly in central dry zone areas that are economically important to the national economy. Wind erosion effects are well recognized in the central dry zone areas for the following reasons:

Table 14.1 Areas of problem soils in Myanmar

No.	Soil type	Area (000 ha)
1.	Saline soil	607.54
2.	Alkaline soil	52.63
3.	Localized problem soils (acid sulfate soil, degraded structure, peaty soils, swampy soils)	300.04
	Total	959.52

- Light-textured Luvisols;
- Scanty rainfall and arid soils throughout the year;
- Unprotected crop fields, lack of natural forest barriers;
- Soil-loosening crops such as major oilseed crops predominate;
- Hot and dry winds suck away meager moisture stored in the topsoils.

In the Kyaukpadaung area, the erosion problem is severe with 50 % of the cultivated land losing its top horizon; this means that most of the fertile soil has been lost through severe sheet and rill erosion. Infiltration and the water holding capacity of these soils are limited. Erosion rates on cultivated land range from 50 t/ha/year for optimum soils on gentle slopes to 150 t/ha/year on slopes of 3–15 % with sandy–loamy or sandy–clay–loamy soil. Many hillsides are almost bare, rocky, compacted and heavily crusted. In the Magway area, there is a high level of erodibility, because of the sandy topsoil. Soil loss was estimated at 30 t/ha/year on better lands with gentle slopes (<3 %) and over 75–100 t/ha/year on undulating lands with sandy loams, surface crusts and low water holding capacity. In the Chaungoo area, the erosion problem follows the same pattern as Kyaukpadaung, mainly in the upper parts of township areas, showing similar severity and rates of erosion and runoff.

Depletion of soil fertility is a serious problem in Myanmar as the most economically important soils of the country are found in these problem areas. It was estimated that about 12.3 % of the total land area situated in the central dry zone faced depletion of soil fertility as well as soil nutrient imbalance. All the agricultural lands on Luvisols in central dry zone areas have depleted soil fertility generated by the following factors:

- Very light in texture (sandy loam to loamy sand);
- Too low in moisture and very high in temperature;
- Rolling and undulating and prone to wind and water erosion;
- Completely deprived of organic matter;
- Yearly cropping without any fertility improvement measures such as green manuring, composting and balanced fertilizer application.

Soil fertility depletion is also found in the Shan Plateau due to water erosion, high acidity and lack of soil improvement techniques. Since this degradation problem is a serious one, it needs to be addressed urgently.

Approximately 1.4 % of the whole country is affected by both salinization and alkalinization that cause land degradation. Coastal strips, deltaic and arid regions are impacted by salinization while alkalinization is confined only to certain areas of the arid region. Types of soils under the salinization category are Gleysols and Vertisols, while Vertisols mainly occur in the alkalinization category. Salinization occurs in the coastal and delta regions due to seawater intrusion. Although heavy rainfall (over 4,000 mm) and flooded rice cultivation annually flush out deposited salts, high tides and high evapo-transpiration in the summer make the soils more saline. Thus, the salinity effect is more harmful to dry season crops. Salinization in the central dry zone is mainly caused by saline groundwater evapo-transpiration which results in salt crusts on the soil surface.

Unfortunately, scanty rain is not enough to wash out the accumulated salts. In addition, using saline irrigation water causes salinization. Alkalinization also occurs in the same way in dry zone areas.

The area of land degradation due to water logging is smaller than other affected areas. Less than 1 % of the total land area found in the Ayeyawady Delta Region is affected by water logging. Although the extent is small, water logging creates adverse effects because of its occurrence in major rice production areas. Thus, the nature and extent of water logging need to be studied to develop preventive measures. Unfortunately, scanty rain is not enough to wash out the accumulated salts. In addition, using saline irrigation water causes salinization. Alkalinization also occurs in the same way in dry zone areas. The area of land degradation due to water logging is smaller than other affected areas. Less than 1 % of the total land area found in the Ayeyawady Delta Region is affected by water logging. Although the extent is small, water logging creates adverse effects because of its occurrence in major rice production areas. Thus, the nature and extent of water logging need to be studied to develop preventive measures.

5 Deforestation

The Dry zone was once a heavily forested region. The heavy cutting of forests to fire brick kilns for construction of stupas and pagodas are said to be primary cause of forest destruction since 11 AD. The inevitable consequence of forest destruction was drastic change in climate, gradually moving from bad to worse. Other main causes of deforestation in Dry zone can be grouped into the following heads:

- Population growth
- Agricultural encroachment
- Increasing livestock population
- Increasing demand for fuel wood

The population, as well as population density, increased in all three Dry zone divisions. The population density from 32 persons per km^2 in 1941 increased to 70 persons per km^2 in 1993. It led to encroachment on reserves and protected areas. The increased population led to extension of agricultural fields and thus encroachment of reserved and protected forests. In addition, it also led to increased demand for domestic fuel as well as industrial usage. The deterioration of land due to erosion and deforestation has made the agricultural production base unstable. The main reasons include increased human as well as cattle population and demand for fuel wood for domestic as well as industrial use. The natural resources of Dry zone are being depleted more rapidly than nature can renew itself.

Fuel wood consumption is one of the main causes of deforestation, and excessive cutting of trees for fire-wood before they are fully grown, leads to the loss of growth potential of the forest stands. Therefore, Forest Department had launched fuel-wood substitution program to reduce pressure on the utilization of wood for fuel. The DZGD since its creation in 1997 had distributed some 100,000 efficient cooking stoves, 9.2 million numbers (7.4 million kg) of briquettes and, the use of 45,000 metric tons of agricultural residue by villagers in the dry zone was recorded over the same period. About 600,000 improved cooking stoves are scheduled to be distributed during the period from 2001 to 2010, and some 108 million kg of briquettes are also planned to be distributed over the same period.

6 Focus on Combating Desertification

Myanmar is a country affected by desertification and drought in some areas. The main area affected by desertification and drought is the Dry Zone in the central part of the country.

The exact causes of desertification are often complex and arise from a variety of factors including settlement of marginal lands, overgrazing, poor management of water and soil, and changing climate with decreasing rainfall and greater incidence of drought.

In Myanmar, the government has stepped up its efforts on preventing land degradation and combating desertification in recent years. The Ministry of Forestry leads efforts to combat desertification with the participation of other ministries but Myanmar is still in the process of developing specific mechanisms for combating desertification. The Government launched a special program and drafted a 30-year Master Plan for greening of this zone (see Sect. 7.1 below).

From the forestry point of view, one of the major tools to fight the spread of deserts is the planting of trees and other plants that retain water, maintain soil quality and micro-climate. Greening work has been carried out in Sagaing and Monywa Districts in **Sagaing Division**, Myingyan, Maiktila and Yemethin Districts in **Mandalay Division**, Magway, Pakokku, Minbu and Thayet Districts in **Magway Division**. Although originally intended for 9 districts, greening work has been extended to 13 districts. Over 80,000 ha of forest plantations have been established, and over 240,000 ha of remaining actual forests have been conserved and protected. The arid zone greening work is being done in accordance with a 30-year Master Plan. During the implementation period, 3.3 million ha of green and lush forests will emerge. The Greening Project will prevent desertification of dry regions.

The Irrigation Department and Water Resources Utilization Department under Ministry of Agriculture and Irrigation have been implementing drinking water supply and irrigation water supply program through judicious utilization of water from surface, rivers, creeks and groundwater sources for food sufficiency and promotion of crop-productions in the Dry Zone.

Furthermore, the tasks for development of wood substituted fuels have also been carried out. With many of the local people using trees for firewood and cooking, the problems on forest depletion/degradation has become acute. To solve this problem, the DZGD under the Ministry of Forestry has endeavored to promote utilization of wood fuel substitutes. The activities for the development of wood fuel substitutes include distribution of fuel efficient stoves, promotion of fuel briquette production and utilization of agriculture residues.

6.1 Problem Soils

In Myanmar, problem soils occupy an area of about 0.96 Mha representing about 7.8 % of total cultivable land stock of 12.31 Mha (Tha Tun Oo 1989). Again, out of the problem soils area, about 18.7 % (0.66 million ha) is occupied by the saline and alkaline soils, most of which are currently under utilization (Table 14.1). The remaining problem soils area of about 0.3 Mha are occupied by acid sulfate soils, degraded soils, peat soils and swampy soils. Among them saline soils and alkaline soils are the most predominant problem soils of the country. Farmers in the problem soil areas grow rice varieties which are moderately tolerant and soil salinity or adjust the sowing time when the crop can stand the salinity level, or wash out the soil with rains or irrigation water. Farmers are aware that gypsum can improve the situation.

The research wing of Myanmar Agriculture Service continues working on the problem to ameliorate the soil at low cost by using crop residue, and other measures.

In the delta region this problem is somehow managed by constructing polders with the assistance of Lower Burma Paddy Land Development Project to protect saltwater intrusion into the field and by washing out the salt from the affected soil with rainwater. The problem in dry zone is expected to gradually improve as its greening program proceeds. Furthermore, pump irrigation projects are also very helpful in preventing salinity problems. The government is also attempting to improve water infiltration in the catchment area by planting trees. Water quality also depends on using level of use of agro-chemicals. But at present Myanmar is not suffering serious effects or water quality since agro-chemical utilization is quite low in comparison with other countries.

6.2 Deforestation and Land Clearing

Many forms of watershed degradation are evident as some form of direct damage to the soil. In the case of soil erosion and deposition, for example, the effects of degradation are manifested in the loss or transfer of soil, which has direct consequences in reducing the productivity of the site. In the case of soil degradation, the effects are manifested in a deterioration in the *in situ* properties of the soil, again with direct consequences in terms of reduced productivity. In the case of ecosystem alteration, however, the immediate consequence is a reduction in the quality and integrity of the entire ecosystem which the land unit under threat supports. The effects will be manifested in a loss of vegetative biomass, a reduction in vegetation productivity and species diversity, and an impairment of habitat for native flora and fauna, as well as the secondary consequences of water and wind erosion and other forms of soil degradation that will be an eventual result of the reduced or impoverished vegetative cover.

Deforestation is here taken to mean the large-scale removal or partial removal of trees from forested areas, which may be deliberate or due to natural causes. Deliberate causes of deforestation include commercial logging, firewood production, clearing for agricultural or timber plantation purposes, "slash and burn" techniques of shifting agriculture, and clearing for such purposes as urban development or the development of infrastructure such as dams, road, railways or mining facilities.

Natural causes of deforestation include wild fire, predation by a variety of pests and parasites, disease, damage by pest animals or grazing animals and human traffic or occupation. Forests shield the soil surface from heavy rainfall, reduce the rate of run-off by increasing the rate of infiltration and as a consequence decrease the amount of flooding, mitigate soil erosion and limit the sedimentation of rivers. They can also act to control landslides and other forms of mass movement of the land surface.

On the other hand, deforestation of watersheds, especially around smaller rivers and streams, can increase the severity of flooding, reduce stream flows by lowering the watertable and increase sedimentation of rivers. Accelerated erosion, soil salinization and impairment of water quality are other common adverse consequences of deforestation. These secondary forms of degradation and ways and means for controlling or mitigating them will be discussed in some detail in other sections of this chapter. The factors contributing to deforestation can all adversely affect land and water resources. The loss of protective tree cover has resulted in erosion, landslides and the silting of rivers and dams, as well as increased flooding downstream. The loss of trees also results in reduced organic matter and the loss of nutrients from the soil by leaching. This leads to further degradation of the quality and extent of forest cover. The destruction of trees on steep slopes and along the banks of rivers and streams can significantly increase erosion and sedimentation problems in the lowland areas of watersheds. In the Asia Pacific region, the rate of deforestation is a major factor contributing to watershed degradation and the increased severity of water related natural disasters. Until comparatively recently, the rate of deforestation in areas of forest has been a cause for much national and international concern.

Land clearing is here taken to mean the large-scale removal of vegetation from woodlands, shrublands and grasslands in order to use them for such purposes as grazing, cropping or irrigation development. This form of activity is practiced in low to marginal rainfall areas where the climatic and soil conditions are not suitable for forest growth but there is potential for large-scale crop or livestock production. As with deforestation, the removal of vegetation makes the land susceptible to water erosion and wind erosion, the latter in particular being a major potential problem in arid and semi-arid areas. Other associated adverse effects may be various forms of soil degradation as a consequence of cropping or irrigation practices, as well as potential invasion and damage by pest species. As is also the case with deforestation, extensive land clearing involves a loss of ecosystem productivity and diversity

Fig. 14.2 Severe gullying and soil loss can follow deforestation and inappropriate cultivation methods

and the destruction of habitat for native flora and fauna. Like the other forms of watershed degradation already discussed, land degradation due to deforestation or land clearing occurs as the direct consequence of poor or inappropriate land-use practices and can be avoided through the application of sound land-use planning and management principles. Good management implies sound overall ecosystem management, a process which requires the striking of a balance between economic objectives for productive land use and ecological objectives for the maintenance of ecosystem quality and diversity. Putting it another way, this kind of approach requires the adoption of an ethic of ecologically sustainable development, which in itself is the essence of the integrated watershed management approach.

Further downslope, as rates and volumes of run-off and quantities of transported sediment increase, larger-scale erosion processes begin to occur (Fig. 14.2).

Gully erosion is essentially a macro-scale version of rill erosion which results in the form of large, incised erosion channels too big to be filled by normal cultivation practices and too wide and deep to be crossed by farm machinery. The classification of gully erosion is usually applied when the depth of the incised channels exceeds 300 mm, although depths of 10 m and more may be experienced under severe erosion conditions (Figs. 14.2, 14.3, and 14.4). Gully erosion involves a number of interacting processes which depend upon climate, soil type, topography and land use. It is initiated in minor drainage lines when normal equilibrium is upset by concentration of water flow or locally decreased resistance of soil to detachment or transport. It develops by two major mechanisms – gully head erosion, which is caused primarily by concentrated flow over the gully head and is the process by which the gully lengthens and moves upslope, and gully side erosion, which can be caused by diffuse over-edge inflow, interflow and groundwater seepage,

Fig. 14.3 Severe gullying may require structural works to reduce flow and trap sediment

Fig. 14.4 Structural gully control works are an effective means for control of sediment movement

undercutting, flow along the gully and raindrop erosion, and is the process by which the gully widens and deepens. As a gully extends upslope the catchment area contributing to head erosion reduces, and uphill movement may eventually stabilize. On the other hand, the rate and amount of over-edge inflow and sub-surface inflow may increase concurrently, enhancing the side erosion process and causing deepening or widening of the gully so long as its capacity to transport eroded material downstream is not exceeded.

Fig. 14.5 Earthworks such as these can reduce runoff and soil loss and retain moisture in situ

Gully erosion can result in the loss of considerable areas of productive cropping or grazing land. It causes significant increases in farming costs, because it makes the operation of farm machinery and the management of livestock more difficult. It also produces serious *off site* effects, resulting from the movement and deposition of sediment, as described below. Because of their size and areal extent, eroded gullies can remove and transport downslope very large quantities of material. If a stream or waterway does not exist downstream to transport this material further down the watershed, a sediment fan will be deposited at its lower end. This can render a substantial area of agricultural land unproductive and may damage farm infrastructure and public facilities such as roads and irrigation or drainage channels. Disturbed flow across the fan deposit may initiate further instability lower down the slope, leading to extended multi-channel or compounded gully development. If the gully discharges into main watershed drainage system, movement of sediment into stream channels will occur, to be eventually deposited further downstream causing river sedimentation or accumulating silt in lakes and artificial reservoirs, with consequential adverse effects on flooding, river and lake productivity and reservoir storage capacity and a general impairment of downstream water quality.

A wide variety of structural and non-structural options is available for the solution of watershed management problems. These may be employed either to control or to rehabilitate land degradation, to control or mitigate the occurrence or effects of water-based natural disasters, or to achieve both concurrently. The more commonly used of these options are briefly described below (Fig. 14.5). More detailed information about them can be obtained from a variety of textbooks and manuals, some of which are listed in the Bibliography which follows this chapter.

Land management measures for the control of land degradation and the mitigation of natural disasters may include a variety of structural and non-structural approaches. The structural approaches comprise a number of small and relatively low-cost mechanical devices whose function is to reduce run-off rates or volumes, to control or retard overland flow or to give protection against erosive or scouring forces. The non-structural measures comprise a variety of farming, cropping and cultivation techniques whose purposes are to maintain a protective vegetative cover, to increase infiltration and to impede overland flow. For the most effective results, a number of these approaches will generally be used in conjunction, utilizing a combination of structural and non structural measures in an integrated fashion to achieve optimal management results.

A range of non-structural and structural or mechanical means is available for the avoidance of mass movement disasters and the mitigation of their effects. There is a variety of structural or mechanical measures which can be applied to reduce the potential for land instability in areas where occupation cannot be prohibited. These measures might include the following:

- preventing or diverting run-off flows around critical sites
- de-watering sites using drainage systems
- planting trees or shrubs which remove sub-surface water by transpiration
- planting deep-rooted vegetation to bind sub-soil material
- underpinning foundations to stable rock
- battering slopes to stable grades
- constructing retaining walls along the toes of critical slopes

The vulnerability of watersheds to land degradation and water-related natural disasters can be reduced by structural works and land treatment measures. Figure 14.4 is an example of a gully plug to stabilize the small stream. The potential impact of these adverse developments or events can be further reduced by the imposition of land-use controls, designed to manage degradation and minimize exposure to the risk of disasters which cannot be avoided. To achieve this objective, legislative controls which empower the relevant government authorities to direct land-use planning policies and practices related to watershed management should be adopted and implemented. These controls should strive to ensure that an effective and comprehensive legal and administrative system is adopted which addresses the problems of land degradation, environmental protection, and the maintenance of ecosystems and is consistent with the principles of sustainable resource development. Such a system requires an integrated approach to the management and protection of natural resources, including land, water, vegetation and human activity, undertaken on the basis of the total watershed. This approach recognized that changes to the natural environment in the upper watershed will influence conditions in the downstream areas.

7 Efforts Undertaken by the Government to Deal with Land Degradation

Since 1960, the Forest Department had established 766,000 acres of plantations, of which 27 % are designated for fuelwood supply of the country. However, most of these plantations were overcut and depleted due to inadequate management and the lack of people's participation for protection.

The National Commission for Environmental Affairs (NCEA) was established in 1990 to advise the government on environmental policies and acts as National Coordination Body (NCB). NCEA is responsible for observation and monitoring of the environment.

In 1994, the Ministry of Forestry (MOF) launched a "Three Year Greening Project for the Nine Critical Districts" of Sagaing, Magway and Mandalay Divisions in the Dry Zone. This was later extended to 13 districts with the creation of new department namely the Dry Zone Greening Department (DZGD) in 1997.

In April 1995, Myanmar hosted the Asia–Pacific Meeting on the follow-up to the International Convention to Combat Desertification in Yangon. In January 1997, Myanmar acceded to the United Nations Convention to Combat Desertification (UNCCD). Even before Myanmar's accession to UNCCD, measures relating to combating desertification have been taken at the local and national levels.

The most evident efforts are the appearance of the National Commission for Environmental Affairs (NCEA) comprising all ministries and the development of National Action Program (NAP). Myanmar has been a signatory of United Nation Convention to Combat Desertification (UNCCD) since 1997. In Combating desertification and drought, the participation of local communities, rural organizations, national Governments, non – governmental organizations and international and regional organizations is essential. A UNDP/FAO project entitled "**Environmentally Sustainable Food Security and Micro-income Opportunities in the Dry Zone**" has been successfully implemented in three districts of the Dry Zone namely, Chaung-U, Magway and Kyaukpadaung townships with community participation. **Small-scale Afforestation and Reforestation Projects** are also been undertaken jointly with some international NGOs such as Yomiuri, Organization for Industrial, Spiritual and Cultural Advancement-International (OISCA-International), Japan International Forestry Promotion and Cooperation Agency (JIFPRO) and Korean International Cooperation Agency (KOICA).

7.1 The Dry Zone Greening Department

The Dry Zone Greening Department was entrusted with the following objectives:

- To green the Central Dry Zone of Myanmar
- To provide the basic needs for forest products of the rural people
- To enhance knowledge and promote participation of the public on environmental conservation and sustainable development
- To promote the socio-economic status of rural communities
- To improve climatic conditions of the environment for supporting sustainable agriculture
- To prevent desertification

The major tasks to be implemented by the Dry Zone Greening Department include establishment of forest plantations, protection of remaining natural forests, initiating development of wood fuel substitutes and management and development of water resources.

The greening activities of the DZGD have also been accelerated. A comprehensive plan for reforestation of Dry Zone for 30 year-period (2001/2002–2030/2031) has been drafted. The plan is divided into six five year short-term plans.

7.2 Forest Plantation

Human overpopulation is leading to destruction of tropical forest due to widening practices of slash-and-burn and other methods of subsistence farming necessitated by famines in lesser developed countries. As a result of increased population, shifting cultivation, fuelwood extraction and other human activities, very little of the original natural vegetation remains and a degraded form of trees were found in many places of the Dry Zone. In the absence of forest cover on the watersheds, severe floods were sometimes occurred causing great damage on both property and human lives. During 2001 rainy season because of high rainfall and flash floods of the sandy streams, several villages were swept away by severe flood water.

Forest Department is fully engaged in **Afforestation and Reforestation Program** including planting trees for commercial purposes, industrial wood supply, fuelwood supply and watershed management. In order to promote the environment, forest plantations are being established in the five critical districts (Kyaukse, Myingyan, Nyaung-U, Yamethin and Maiktila). The following is a set of criteria for forest plantations: –

- Only local variety seedlings are to be used in forest plantations
- Only over 70 % survival rate are to be considered for successful plantation
- Forest plantations must supplement 5–10 % of the wood-fuel needs of the Dry Zone

The government has also made continuous efforts to sustain forest productivity in cooperation with FAO, aiming not only to improve environment and food security, but also to efficiently utilize rural energy through establishment of community wood lots. Myanmar Forest Policy (NFP), has identified six imperatives in its text for sustainable forest management (SFM). One of the six imperatives is to satisfy the basic needs of people for timber, firewood, food, shelter and recreation. Moreover, Myanmar's effort to protect and conserve forestlands and resources will result in environmental balance, which, in turn will support the improvement of food production and social setting. The forestry sector of Myanmar is now in the process of developing NFPs for the whole country and for the Central Dry Zone greening within the context of the national sustainable development strategy. In NFP, the existing 50 % coverage of forests over the total land area of the country are to be maintained, of which 40 % would be designated as Permanent forest Estate (PFE) and the rest, 10 % would be assigned as conversion forests for possible needs for agriculture and other uses for the State.

7.2.1 Decision-Making: Legislation and Regulations

In order to manage lands under forest cover in an integrated approach forest management plans for 62 civil districts covering the whole country were recently reformulated and updated based on SFM principles. With emphasis on environmental conservation and improvement of soil fertility status, a new institution entitled "Dry Zone Greening Department" was recently set up (see Sect. 7.1) to implement the major tasks of protection, reforestation, water resources development and fuel wood substitution in the desert-like dry zone of Central Myanmar.

A major breakthrough in Myanmar Forestry was also made in 1995 by issuing Community Forestry Instructions to promote and encourage people participation and decentralization in forest management in addition to policy, legislative and institutional updating and reforms in the 1990s.

In 1993, Forest Conservation and Management Committees at all administrative levels were formed to implement integrated forestland management to prevent and check land degradation, deforestation as well as to strengthen multi-sectoral planning, decision-making and participation.

The government's endeavors for the promotion of the best possible land use and sustainable management of land resources since UNCED include:

- To facilitate the development of a market-oriented economy, "the Privatization Commission" to oversee and ensure the successful implementation of the privatization process was formed in January 1995.
- In forest sector, the Government is inviting foreign investments in forestry either in joint ventures or 100 % investment, making agreements with Forestry Department.

Forest Law of 1992 has provisions for private sector involvement and investment in establishing forest plantations.

In Myanmar, forestry (about 51 % of the total Land area) and agriculture (about 27 %) are the two main sectors with regards to the management of land and land-based resources. The State, with view of enhancing sustainable agriculture, is reclaiming cultivable wasteland and fallow land into agriculture farmlands, while measures are being undertaken to increase per unit yield. Regarding vast areas of cultivable wasteland (idle land that could be cropped), it is possible to undertake land reclamation encroaching on with forestlands. However, there exists agricultural encroachment into forestland. Some 151,420 ha of permanent agriculture are found to have been cultivated in forestlands. In Myanmar, intrusion of permanent agriculture into forestlands is not a significant issue.

While agricultural land use is still manageable outside forest lands, Forest Department is in the process of increasing the existing permanent forest estate from the present status of about 18 to 40 % as stipulated in Myanmar Forest Policy, 1995.

7.3 Dry Zone Water Supply Program

Water is scarce in the Dry Zone due to low annual rainfall. It is believed that 8,042 villages (2,454 villages in Sagaing Division, 1,469 villages in Magway Division and 4,119 villages in Mandalay Division) are facing water shortage.

Water supply is one of the main activities of rural area development program carried out in the current short-term 5 year (2001/2002–2005/2006) plan. Works for supplying water include ground-water tapping projects and river-water pumping projects for both drinking water and irrigation water supplies. These projects are being carried out collectively by a number of governmental departments.

The Development Affairs Department under the Ministry for Progress of Border Areas and National Races and Development Affairs is undertaking the task of providing adequate water supply in the rural areas. The Ministry has drawn up the 10-year water supply project and has now been implementing to supply water for Sagaing, Magway and Mandalay Divisions.

7.4 Other Programs and Projects

Some technical assistance projects are being provided by ICIMOD. In Myanmar as in all developing countries mountain ecosystems are susceptible to soil erosion, landslides and rapid loss of habitat and genetic diversity. Unemployment, poverty, poor health and poor sanitation also prevail among mountain dwellers. Most mountain areas are experiencing environmental degradation. Proper management of mountain resources and socio-economic development of people need immediate action. It should aim at preventing soil erosion, increasing the amount of tree and plant life, and maintaining the ecological balance in mountains. For local communities and indigenous people, education, health care and energy should be provided. The people also need more opportunities to earn livelihood from such activities as tourism, fisheries, environmentally sound mining, cottage industries, and processing of medical plants.

Myanmar's major mountainous areas as part of Hindu Kush-Himalayas are found in Chin, Kachin and Shan States. Myanmar has been the member country of International Mountain Development (ICIMOD) since the early 1990s. Biodiversity study in Pi-daung Nature Reserve in Upper Most Myanmar of the Kachin State is being undertaken jointly by Myanmar and ICMOD. An experiment on slope land agriculture technique is also underway in Northern Shan State, which is financed by ICIMOD. Furthermore, a project proposal for the management of mountain biodiversity in the Hindu Kush-Himalayan Region has been submitted to the Myanmar Government by ICIMOD. In sum, Myanmar is placing emphasis on the sustainable development of mountainous areas in close cooperation with ICIMOD.

7.4.1 Biodiversity

Myanmar has been divided into nine bio units, each representing a different agro/eco-climatic zone. The country is endowed with a diversity of flora and fauna. It has been identified that there are about 7,000 plant species, more than 300 mammals and 400 reptiles, and 1,000 birds species. The major development in biodiversity conservation is the promulgation of the "Protection of Wildlife, Wild Plants and Natural Areas Law" in 1994. The wildlife legislation as against in contrast to the old one has assumed the modern approaches in biodiversity conservation. The Law has greatly enlarged the scope of protection accorded to the animals. Among them, birds and mammals are prominently included. The 1994 wildlife legislation declares complete protection for 39 mammals, 50 birds and 9 reptiles species, normal protection for 12 mammals, 43 birds and 6 reptiles species; and seasonally protected species including 2 mammals and 13 birds.

8 Practical Methodologies for Combating Land Degradation

At present, the extent and locations of land degradation in Myanmar are mainly derived from aerial photograph interpretation and reconnaissance soil survey using topographic maps. From these maps, the severity of water erosion was deduced. No comprehensive studies concerning the severity and extent of various forms of land degradation have been conducted because there has been no specific demand by any users for land degradation data in detail. Moreover, there are no means and financial resources to conduct a specialized study of land degradation at a national scale by the Land Use Division (LUD). In spite of this, LUD conducted a thorough examination of land degradation in the surveyed area during its normal detailed planning and classification of various degrees of land degradation according to international standards.

Current land management policies focus on:

- Reclamation of cultivable wastelands.
- Construction of dams for irrigation.
- Environmental protection and conservation.
- Vertical expansion of agriculture.
- Production of agro-forestry/community forestry.
- Creation of income-generation opportunities.
- Restoration of degraded forestlands for soil improvement.

Table 14.2 Extent of water erosion within the dry zone of Myanmar

Type of water erosion	Extent (%)
Slight rill erosion	7.2
Slight to moderate rill erosion	38.2
Severe sheet and sheet erosion	26.2
Topsoil completely removed	0.4

Note: Total water erosion affected area = 72 % approximately

8.1 Mapping of Degraded Land, Availability, Scales and Methods Used

At present, mapping is carried out by the LUD. The three types of major maps produced are: agro-ecological zone maps, soil maps and soil erosion maps at the national level. Soil maps based on land topography are produced at the state/division level. Mapping is based on 16:1 scale, which is used by the Department of Settlement and Land Record, and 1:1, 1:2 and 1:4 scales for military maps. Data on the shifting cultivation area are produced using the Forest Inventory Maps generated by the Forest Department, Ministry of Forestry.

Types of water erosion and their affected areas (Table 14.2) are deduced from medium-scale soil survey maps produced by LUD and the Myanmar Agriculture Service (MAS), Ministry of Agriculture and Irrigation (MOAI). Geographic information systems (GIS) have been used recently for the production of soil maps to clearly explore soil degradation condition in central dry zone areas. The usage is unsophisticated due to lack of software as well as human resources and financial aid.

8.2 Prediction and Modeling for Land Degradation Development

Slope maps, which are essential for erosion mapping and land capability mapping, have never been produced in Myanmar for so large an area. The methodology has been contributed by the Watershed Management for Three Critical Areas Project. After the slope maps have been produced for the entire project area at 1:633,600 scale, algorithms to produce erosion susceptibility data are formulated using FAO procedures. Management practices that conserve soil moisture or increase soil water holding capacity of the soils employ soil conservation techniques. For the time being, LUD is conducting measurement of the erosion rate on an experimental basis mainly in the central dry zone areas. Treatments include bare soil plots, contour plantation plots, plantation plots along the slope and natural vegetation plots. Soil loss findings from the tested plots are given in Table 14.3.

Table 14.3 Rate of soil erosion under different levels of soil cover

Testing period (During wet season)	Bare soil (no grass)	Plantation plots along contour	Plantation plots along slope	Natural vegetation	Rainfall amount per rainfall event
26 June to 7 October	0.63 t/ha	0.21 t/ha	0.22 t/ha	0.18 t/ha	3.8–2 mm 17 rainy days with total rainfall of 200 mm

Data from Land Use Division, Ministry of Agriculture and Irrigation (U Kyaw Yee, personal communication 2011)

9 Challenges

There is widespread land degradation as population increase. Demands for new and inappropriate land uses and husbandry practices are on the increase. A proper land use policy is the key to control land degradation due to improper land use and to ensure a sustainable use of land according to their productive capabilities and constraints. Up to now such a policy is lacking.

Efforts to combat desertification and arrest and reverse land degradation are still in progress in Myanmar. There are still many things that we don't know about the degradation of productive lands and the expansion of desertified land. We would like to achieve control technologies to reduce the rate of land degradation/desertification. From the scientific and technological point of view, we have low understanding of technologies on control of DDLD due to the needs for diverse levels of education as well as the lack of sufficiently proactive machinery and insufficient conversation between decision makers, scientists and media.

The main challenges to sustainable agriculture and rural development in Myanmar, could be (a) shortage of competent human resources in research and development activities, (b) lack of financial and or physical access of the farmers to the available inputs, (c) development and transfer of appropriate and sustainable agro-technology which are environmentally friendly, and (d) lack of marketing system that guarantee a fair share of benefit for all parties involved in the system. For the time being, only outdated aerial photograph interpretation and soil survey data (semi-detailed and topographic) are available, thus there is a need for improved methods to identify and collect more accurate information concerning the severity and extent of land degradation in Myanmar. Myanmar needs international cooperation and coordination among the network's countries for the establishment of a land degradation database, which will be of great benefit to land development.

To prevent land degradation, reliable and up-to-date information on the potential and constraints of the various agro-ecological zones and the production potential of each of them based upon systematic and quantitative land suitability and productivity assessments are required. A general national soil maps was made in the 1960s, but since then only little progress was made towards the creation of a national soil/land data base, due to financial and technical reasons.

Young staff members urgently need training, as experienced soil scientists are getting to or are past retirement age. Myanmar needs technical and financial assistance in this particular field. To increase awareness and participation of private sector in promoting sustainable agriculture, the government has initiated a number of activities, through farmers' meeting, pamphlets, radio broadcast, television, and field days. But much more needs to be done and help from the donor community including NGOs, will be needed over the next 10–15 years.

10 Conclusions

Land degradation has been a severe threat to sustainable agriculture and forest development for 50 years. Land degradation due to wind and water erosion, salinization and alkalinization is of particular concern. According to the current land utilization, about 11 million ha or 16 % of the total land area is under cultivation. Since a total of about 18 million ha is estimated as suitable for agricultural purposes, some 7 Mha of new land can be brought under crop cultivation and livestock farming. In bringing new land under agricultural use, it is important that scientific techniques for land evaluation and land-use planning are used to ensure the suitability and optimum use of land. In agricultural planning, land evaluation sets up a link between the basic survey of resources and the making of decisions on land use. As part of the land-use planning process, the Land Resources Information System is vital to ensure that environmentally valuable lands are not encroached upon and that adverse environmental impacts can be avoided.

To ensure conservation of the resource base, effective programs should be designed to address the following constraints in agriculture:

- Low productivity due to agro-climatic conditions;
- Low productivity due to water shortage;
- Low productivity due to soil degradation, irrigation-induced water-logging and salinity in the dry zone.

A number of agricultural research stations and centers are presently carrying out research on plant varieties, cropping patterns, irrigation techniques, water storage techniques and soil analysis. The programs and activities of these centers should be reviewed to ascertain their effectiveness and to assist in the formulation of new programs that can address key productivity constraints

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Chapter 15
The Philippines Action Plan to Combat Desertification, Land Degradation, Drought and Poverty

G.M. Castro Jr.

Synopsis The Philippines is a country made up of islands, some large and some small. It is an agricultural country with mostly steeply sloping land that was cleared of forest to become cropland – principally for food crops to support the rapidly increasing population. Over time, soil loss and nutrient depletion have reduced the productivity of the land. Innovative approaches that provide soil protection and improve both livelihoods and human nutrition have been trialled. This chapter summarizes the results of some of them.

Key Points

- The Philippines, one of the largest island-groups in the world with 7,107 islands and islets, is strategically located within the area of nations that sweeps southeast from Mainland Asia across the equator to Australia. Approximately 27.3 % of the Philippines is vulnerable to drought, alternating with yearly floods and typhoons, causing serious land degradation and declining land productivity. These are provinces located in Type 1 climate, which are typhoon and drought prone and are generally vulnerable to El Nino – 6.60 million hectares are in Luzon, 1.41 million hectares (Mha) in the Visayas. There are specific provinces in Mindanao that are likewise becoming vulnerable to seasonal dryness caused by natural drought and El Nino phenomenon.
- It is estimated that soil erosion carries away a volume of soil 1 m deep over 200,000 ha a year. On-site soil fertility losses in the Philippines due to unsustainable land management, as per 1989 World Bank estimates, is to be around US$ 100 M, equal to one per cent of Philippine GDP per year. The quality and management of land resources in the Philippines has become of serious concern because of exponentially increasing population and the need

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to expand agricultural production to marginal areas while ironically converting prime agricultural lands to non-agricultural uses.
- Acknowledging the Philippines' increasing vulnerability to drought and land degradation as a result of increasing recurrence of dry spell and alternating incidence of El Nino and La Nina as well as poor management of land, freshwater, and watershed resources, the Philippine National Action Plan (NAP) was formulated and implemented by the Philippine Government in 2004. The NAP is an expression of full and unqualified commitment of the Philippine Government in the effective and accelerated implementation of the programs and project activities to combat desertification, land degradation and poverty in the identified drought vulnerable areas of the country. It is a working document for the convergence of actions of the Departments of Agriculture (DA), Environment and Natural Resources (DENR), Science and Technology (DOST) and Agrarian Reform (DAR).
- The NAP is water-centered and focused on the sustainable management of Critical Watershed Areas located in seasonally dry/arid areas, which are suffering from food insecurity. It is composed of two major thematic programs – Sustainable Agriculture and Marginal Upland Development and Integrated Ecosystem Management. These thematic programs have five components – Land and Water Technology Development, Local Governance and Community Initiatives, Data Base Development and Harmonization, Information, Education and Communication, and Enabling Policy Development. All of these aim to mainstream agriculture and rural development programs that will prevent the incidence and spread of desertification in deprived communities living in seasonally arid degraded lands.

Keywords Desertification • Land degradation • Drought • Soil erosion • Watershed • Poverty alleviation • Food security • Water • Archipelago doctrine • Islands

1 Country Background

The Philippines, one of the largest island-groups in the world with 7,107 islands and islets, is strategically located within the area of nations that sweeps southeast from Mainland Asia across the equator to Australia. Its boundaries are formed by three large bodies of water: on the west and north by the South China Sea; on the east by the Pacific Ocean; and on the south by the Celebes Sea and coastal waters of Borneo.

The total land area of the Philippines is 300,000 km^2 or 30 Mha. It constitutes 2 % of the total land area of the world and ranks 57th among the 146 countries of the world in terms of physical size. The Philippines, advocates the archipelago doctrine, as such it gains exclusive to all resources living or non-living in and at the bottom of an area of about 276,000 square nautical miles.

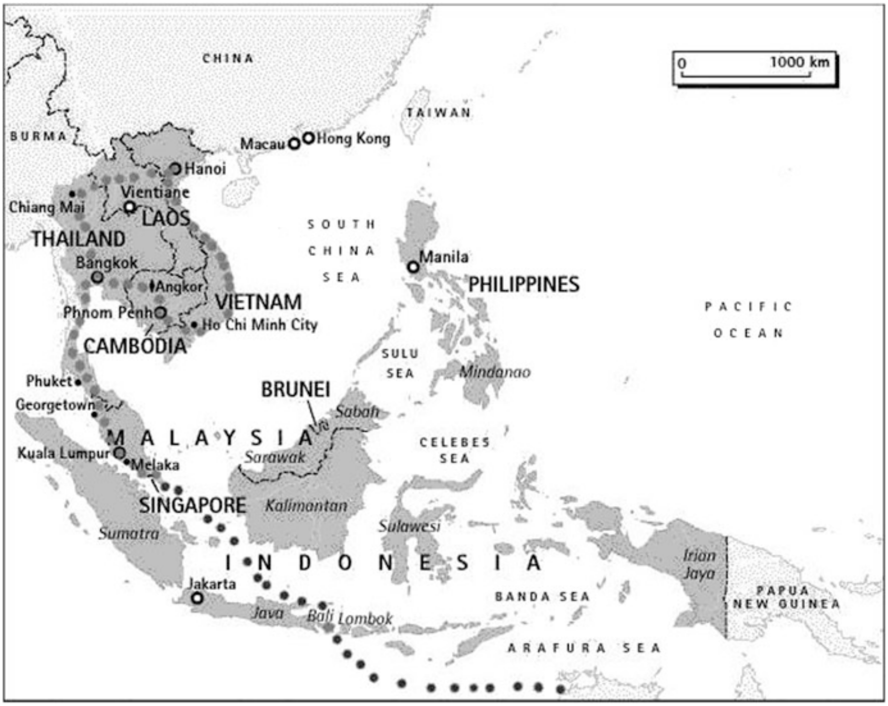

Fig. 15.1 Location map of the Philippines within SE Asia

1.1 Population, Growth and Distribution

The annual growth trend of the Philippine population stood at 2 % in the first half of the twentieth century, surged in the 1950s, and reached a maximum of 3 % in the 1960s. Growth rate gradually declined in the next two decades at just above the 2 % level since then. The 2000 Census placed the Philippine population at about 76.5 M. The National Census Office predicts that the Philippine population is expected to reach 105.5 M by 2020. The population growth rate is still high by regional standards and this extends the strain on limited resources to accommodate such population increases (Figs. 15.1 and 15.2).

The Philippines is divided into three major island groups:

- Luzon, with an area of 141,000 km^2;
- Mindanao, with an area of 102,000 km^2; and
- Visayas, with an area of 57,000 km^2.

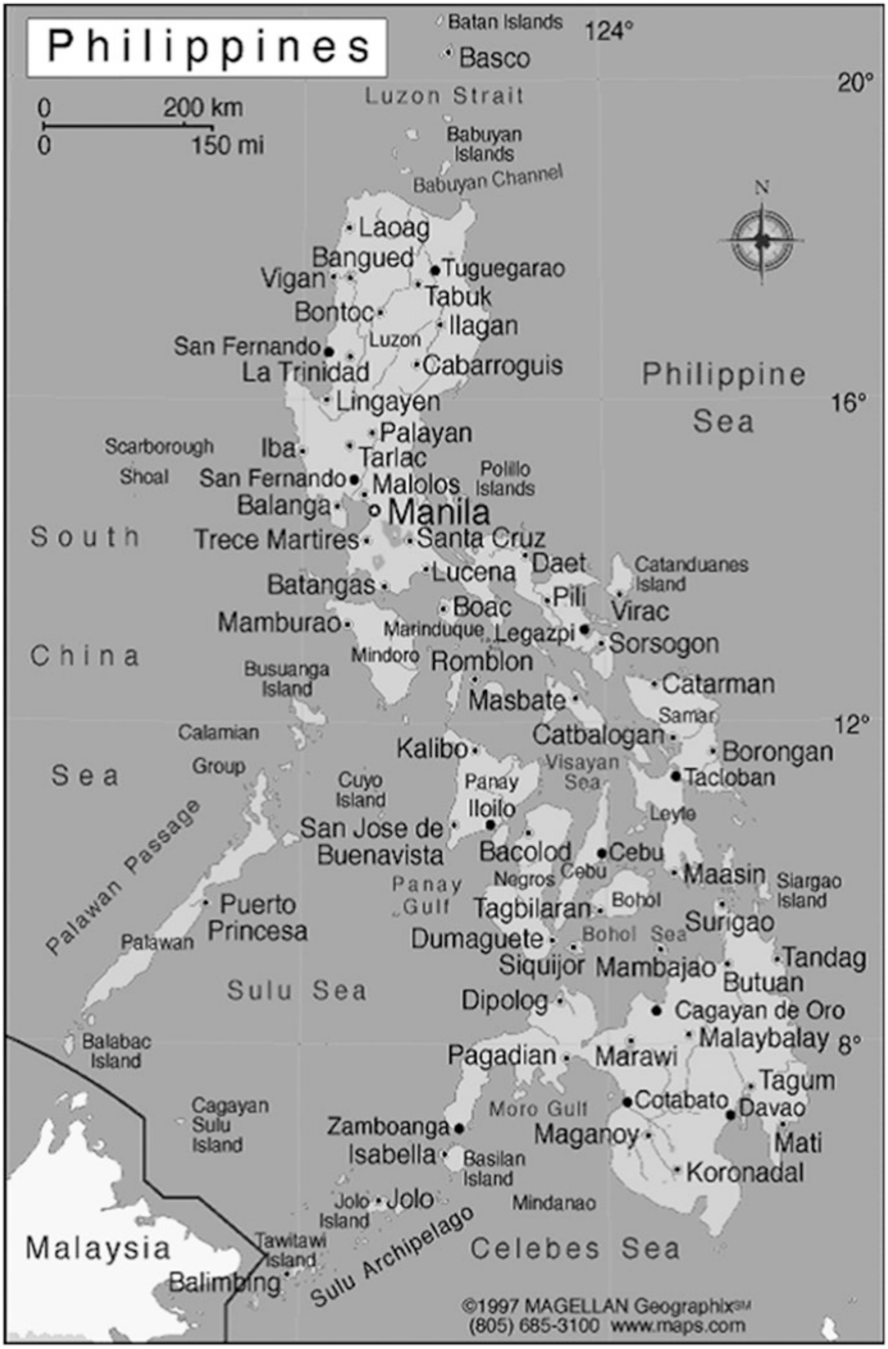

Fig. 15.2 The Philippines is an island nation

Table 15.1 The four major climate types in The Philippines

Type I:	Two pronounced seasons with maximum rain period from June to September and a dry season that lasts from 3 to 6 or 7 months
Type II:	No dry season with a very pronounced maximum rain period from December to February
Type III:	No pronounced maximum rain period with a short dry season lasting only from 1 to 3 months
Type IV:	Rainfall more or less evenly distributed throughout the year

1.2 Climate

Based on the seasonal rainfall distribution, the climate of the Philippines is classified as set out in Table 15.1.

The tropical cyclone season in the country is from June to December, with the months from July to September having the most frequent occurrence of more than three cyclones each month. Annual relative humidity ranges from 75 to 86 % and annual mean temperature is between 19.20 and 28.20 °C while annual rainfall ranges from 914 to 4,358 mm.

1.3 Land Resources

The Philippines is an agricultural country. The total land area of the Philippines is about 30 Mha, 47 % of which is agricultural land. A total of 15.8 Mha are classified as forest lands and 14.2 Mha are classified as alienable and disposable lands. Of this 14.2 Mha, about 13 Mha (93 %) are devoted to agriculture of which 6.1 Mha are highly suitable for cultivation. The main crops are: Food grains occupying 4.01 Mha, other food crops account for 8.33 Mha and non-food crops occupy 2.2 Mha. In the Philippines, prime agricultural lands are located around the main urban and high population density areas.

2 Philippine Scenario on Land Degradation, Desertification and Drought

The Philippines, a tropical country, is well endowed with rich natural resources and is known to host biologically diverse habitats composed of universally unique biological plants and animal life. In addition, the agricultural lands of the Philippines are very fertile and productivity enabling farmers to plant different crops throughout the year. However, because of natural, human-induced and policy-induced factors that includes poor drainage, volcanic eruptions, extensive use of chemical fertilizers, increasing demand for human settlement, and poor enforcement of land use policies and monitoring of land use conversion, incidence of desertification, land degradation and drought has become a prominent and recurring environmental problem.

2.1 Land Degradation

The nature of land degradation in the Philippines can be summed up as being in two broad categories:

2.1.1 Accelerated Water Erosion

Deforestation and unsustainable land management in the uplands make topsoil vulnerable to go with water runoff after a rainfall event. Once the rich top soil is gone, this creates a cycle of poverty, resource exploitation, and under development.

2.1.2 Nutrient Mining and Soil Fertility Decline

There is declining trend in productivity despite fertilizer applications under modern intensive farming methods.

About 45 % of the arable lands in the Philippines have been moderately to severely eroded, triggering the movement of subsistence farmers to marginal lands with the hope of meeting their day to day food requirement. Approximately 5.2 Mha are seriously eroded resulting to 30–50 % reduction in soil productivity and water retention capacity. This situation will predispose the degraded lands to drought and other water availability problems.

3 Forms, Extent and Distribution of Land Degradation

3.1 Soil Erosion

The most common type of land degradation in the Philippines is soil erosion posing a detrimental effect on soil physico-chemical and biological properties. This makes the land less suitable to crop production or in some cases of severe erosion result to total loss of soil less suitable to crop production or in some cases of severe erosion result to total loss of soil productivity. Moreover, it can disrupt utilization of public utilities. There are various degrees/classes of soil erosion ranging from no apparent to severe in the Philippines (Table 15.2).

Table 15.2 Area distribution of erosion classes by island grouping (in million ha)

Island grouping	Erosion class										Totals	
	No apparent		Slight		Moderate		Severe		Unclassified*			
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Luzon	4.1	57.7	4.1	46.6	4.1	48.2	1.7	32.7	0.2	50.0	14.2	(47)
Visayas	1.2	16.9	1.7	19.3	1.5	17.0	1.1	21.2	0.1	25.0	5.6	(19)
Mindanao	1.8	25.4	3.0	34.1	2.9	34.1	2.4	46.1	0.1	25.0	10.2	(34)
Philippines	7.1	23.7	8.8	29.4	8.5	28.3	5.2	17.3	0.4	1.3	30.0	(100)

Source: Bureau of Soils and Water Management (1993)
*Unclassified erosion refers to quarry, river wash, and open pit mines

Other types of soils degradation associated with soil erosion are loss of soil nutrients and or organic matter, river erosion, flooding and water logging (Fig. 15.3).

3.2 Soil Mining and Decline of Soil Productivity

The long term and continued use of urea "alone" resulted in serious nutrient imbalance and contributed to the actual silent soil degradation widely known as soil mining. The general trend based from soil analysis covering a 20 year period indicated very active soil mining where there is now an increasing number of plant nutrients required to sustain plant growth.

4 Causal Factors of Land Degradation

4.1 Natural Causes

4.1.1 Topographic Variations and Problem Soils

The Philippines is an archipelago with topographic variations in its various islands. It has several mountains/hilly lands present all over the country which are experiencing decreased in land cover, thus, making them more prone to soil erosion. Furthermore, problem soils are dominant in the Philippines characterized by steep slopes, poor drainage, coarse textures and fertility limitations.

4.1.2 Volcanic Eruptions

There are more than 200 volcanoes in the country and four major volcanic belts, namely: the Westerly Convex Volcanic Belt in Luzon, Easterly Convex Volcanic Belt, Westerly Volcanic Belt and Southeasterly Volcanic Belt.

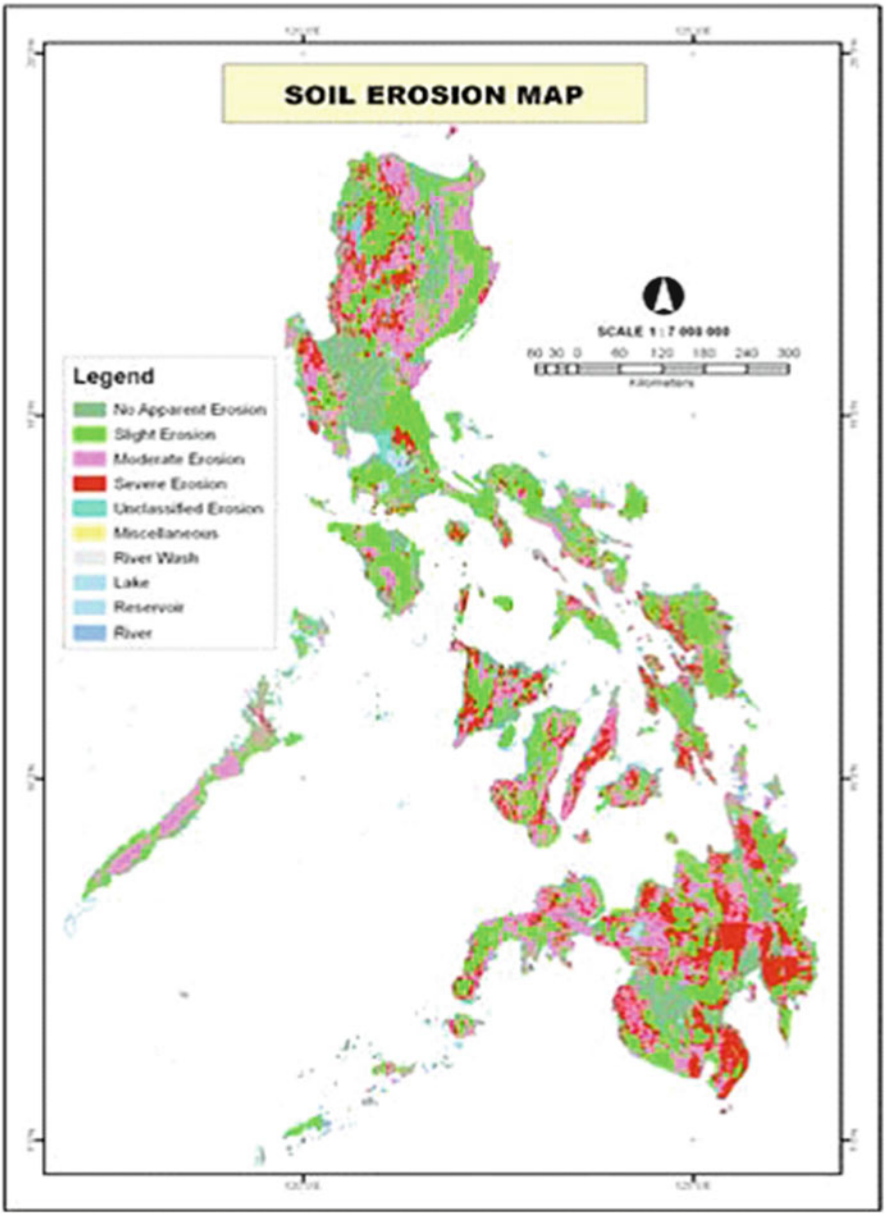

Fig. 15.3 Soil erosion takes many different forms as this map shows. Severe erosion (shown in *red*) is more common in the south

Table 15.3 Soil loss for various land uses and slopes (tons/hectare/year)

	Slope category (%)	
Land use	18–30	>30
Rice	50	100
Corn with fallow	50	150
Other agriculture	25	50
Forest	1	1

One of the major volcanic eruptions is that of Mt. Pinatubo in 1991 emitting enormous amounts of ash laden steam clouds reaching as high as 20 km above the event. An estimated 6 B m^3 of pyroclastic materials were deposited over a 4,000 km^2 area including the eight major river basins that drain the volcano. The interim effect of this eruption is the occurrence of heavy ashfalls and *lahar* (lava) making vast tracts of lands planted to rice and sugarcane in Central Luzon unfit for agricultural production and several residential areas unsuitable for human settlement. Furthermore, every year, particularly during the wet season, heavy rainfall continues to erode the pyroclastic material deposited on the slopes of the volcano causing fast-moving lava to wreak havoc and severe damage on an estimated 300,000 ha comprising mostly of residential and agricultural communities.

4.2 Human-Induced

Primary causes of land degradation have been identified as:

4.2.1 Intensive Logging

Forest cover in the Philippines decreased from 34 % in the 1970s to 22 % in 1987. The 1987 forest resource inventory showed a forest cover of 6.6 Mha leaving 10.8 Mha of possible degraded forest lands. Estimates and distribution of degraded lands are highly variable. Most of the area is mountainous and faces severe erosion problems with vegetation removal. The underlying causes of deforestation are rooted in a complex web of social, economic, and institutional problems both within and outside the forestry sector.

4.2.2 Unsustainable Agricultural Practices in the Sloping Uplands

This is due to intensification of agricultural land use without compensating investments in soil conservation and fertility. A major causal factor is upland migration (Table 15.3).

Table 15.4 List of farming and other technologies adopted by farmers in Lantapan, Bukidnon

Sustainable farming practices	Specific technology/approach
Diversified farming/multiple cropping	Intercropping
Sloping land agricultural technology (SALT*)	Contour plowing, contour hedges, any contour barriers, SALT 1,2,3 and 4 (including livestock)
Soil and water conservation (SWC)	Mulching, cover cropping, minimum tillage, drip irrigation
Integrated crop management (ICM)	Integrated pest management (IPM), Soil testing, crop rotation, Faming technology system (NFTS)
Farm forestry	Diversification of tree species (exotic, indigenous, fruit, nuts)
Farm waste management and recycling	Composting, segregation (liquid and solid)
Clean energy briquette production	Using rice hulls, charcoal, farm waste
Community clean and green projects	Riparian improvement, water quality monitoring

Source: Nguyen et al. (2006) (See Watson and Laquihon 1993)

4.2.3 Population Growth

The Philippine population is growing at an annual growth rate of 2.3 %. This increase in population is accompanied by increasing requirements for food, clothing and settlements. To improve crop yield, extensive use of chemical inputs such as inorganic fertilizers, herbicides and pesticides has been popularized which left the soil very acidic and unfit for production in the long run. While the demand for meat and meat products continue to increase, grazing lands for cattle, goat and other ruminants are extensively utilized.

The increasing demand for human settlement and other non-agricultural purposes has contributed to the great loss of prime lands. This resulted to the opening of ecologically fragile lands. Approximately 74 % of the sloping uplands are actively used for subsistence farming in order to augment the demand for food supply and increase income. Soil erosion is a major constraint to sustaining food crop production on sloping lands in the Philippines. Degradation of land resources, where the livelihood of farming communities depends on soil is a serious problem. In tree depleted landscapes with poor soils and risk-prone environments, farming systems based on monoculture are not sustainable, but integrating trees, and contour hedges to control soil erosion, increase income of farmers, and improve farm environmental services (ES) particularly on carbon sequestration, offer better prospects and a viable option for smallholders. Table 15.4 lists some technologies adopted by farmers in Lantapan.

Soil erosion, soil infertility, poor tree cover, and poor farm productivity are major barriers. Integration of trees into intensive vegetable farming systems with minimal negative interaction can increase productivity, profitability, nutrient use efficiency and ES.

4.3 Policy-Induced

Inefficiency and improper land utilization can be attributed to the lack of a rational, comprehensive and updated national and local land use plan that will delineate lands for agriculture, biodiversity, human settlements and industries/ commercial centers. Non-delineation of lands resulted to illegal conversions of agricultural lands to nonagricultural lands, displacements of rural communities and entry of commercial establishment in some ecologically fragile lands. Proving in court that the land is illegally converted would require a very long process of litigation.

Boundary between forestlands and alienable and disposable lands are not clearly delineated resulting to complication in enforcement of land use laws and monitoring of land use changes. Illegal logging, shifting cultivation, and encroachment of dwellers in forested areas are rampant. Other effects would include low land productivity, squatting and possible establishment of industries and settlements within ecologically critical areas. In areas where zonings are in place, zoning ordinances are not strictly implemented partly because of the absence of police power of concerned government agencies in enforcing land use and land conversion laws.

5 Drought

Drought is a recurring event in the climatic system that is dictated by a water supply and demand phenomenon. Simply defined, it is the lack of sufficient water supply to meet requirements. Drought can strike any region at any time with varying degrees of severity resulting in desertification. Climatological studies showed that major drought events in the Philippines are associated with El Niño occurrences or warm episodes in the central and eastern equatorial Pacific. Four major drought events in the Philippines that occurred in the twentieth century: 1982–1983, 1986–1987, 1989–1993 and 1997–1998.

5.1 Distribution and Extent of Drought Hotspots

Vulnerable areas experiencing seasonal aridity and drought simulating the conditions and effects of desertification processes include the following: Major corn and feed grain–producing areas located within the moisture-deficit, rain shadow areas of Region 11 (General Santos City, South Cotabato, Sarangani and portions of Davao del Sur in the southern tip of Mindanao Island). Region 2 in the Northern tip of Luzon (sand dunes of Ilocos Region, significant portions of Tuguegarao in the Cagayan Valley). Provinces in the western portions of the country experiencing Type 1 climate characterized by two pronounced seasons, dry and wet, with maximum rain period from June to September due to prevalence of Southwest monsoon. Seasonal aridity is exacerbated by the increasing incidence of El Niño, which is now occurring at a 2–3 year cycle from previous 5-year interval. The water stress periods in the seasonally arid/semi arid areas are extended to 4–9 months depending on the intensity of drought or El Niño dry spell (6–9 months).

6 Efforts to Combat Land Degradation and Mitigate Drought Effects

6.1 Farmer's Initiatives

In a study conducted by PCARRD in 30 *barangays* of 9 regions in the country, 10 *barangays* reported that residents became more hardworking and resourceful in response to drought incidence. Planting of other crops such as vegetable and watermelon were done in order to augment income. In addition, organizations at *barangays* level such as cooperatives, farmers, women and youth organizations implemented other income-generating activities such as sewing and selling rags and dresses, carpentry and construction jobs in other places.

Adaption of SALT technology and approaches has been embraced in pilot trials and it is being replicated and scaled up. SALT is a technology package of soil conservation and food production that integrates several soil conservation measures (Watson and Laquihon 1993). Technically, SALT is a contour farming system. The method involves the planting of field crops in bands 3–5 m wide between double rows of nitrogen-fixing shrubs and trees planted along the contour. These minimize soil erosion and maintain the fertility of the soils. Field crops include legumes, cereals, and vegetables, while the main perennial crops are cacao, coffee, banana, citrus, other fruit trees and forest trees. SALT helps considerably in the establishment of a stable ecosystem. The double hedgerows of leguminous shrubs or trees prevent soil erosion. Their branches are cut every 30–45 days and incorporated back into the soil to its fertility. The crop provides permanent vegetative cover which aids the conservation of both soil and water. The legumes and perennial crops maintain soil and air.

SALT helps considerably in the establishment of a stable ecosystem. The double hedgerows of leguminous shrubs or trees prevent soil erosion. Their branches are cut every 30–45 days and incorporated back into the soil to improve its fertility. The crop provides permanent vegetative cover which aids the conservation of soil and water. The legumes and perennial crops maintain soil and air temperature at levels favorable for the better growth of different agricultural crops. The recommended hedgerows species used in SALT are *Flemingia macrophylla*, *Desmodium rensoni*, *Gliricidia sepium*, *Leucaena diversifolia*, and *Calliandra calothyrsus*.

Aside from its soil and water conservation effect and its role ensuring sustainable source of food to smallholder farmers, SALT is also seen to be an effective paradigm shift from the traditional destructive farming practices (e.g., "kaingin" system or swidden cultivation) of upland farmers and forest migrants to more sustainable farming systems in the uplands. "Kaingin system is observed to be one of the major factors influencing soil erosion in the uplands and siltation of lowland areas in most of the project sites". If this SALT technology will be widely adopted by the majority of upland farmers – particularly the beneficiary – communities and people's organization partners, this can drastically reduce siltation in downstream areas and coastal waters. In a short period of time, the technology can improve soil and water quality and the rejuvenation of forests (re-greening effects).

A 10-year study (Watson and Loguihon 1980–1990) showed that a hectare of land farmed according to SALT can increase an upland farmer's income dramatically. Even in the first 2 years of the study, SALT yielded gross incomes which were much higher than the $49.00/crop/ha of farms using traditional practices (burning, plowing, constant weeding, and chemical fertilizers). When the permanent crops (coffee, cacao, banana, etc.) started producing the annual gross income from SALT further increased to $571.49/ha in 1984 and $622.38/ha in 1985 (Box 15.1).

Box 15.1: Use of SALT in Practice – Step by Step

First contour lines are established by using an A-Frame, a simple device for laying out contour lines across the slope. It is made of a carpenter level and three wooden or bamboo poles nailed or tied together in the shape of a capital letter A with a base of about 90 cm wide. The carpenter's level is mounted at the cross bar. The contour lines are spaced 4–5 m apart.

1. One-meter strips along the contour lines are plowed and harrowed to prepare for planting. Stakes which were driven while using the A-Frame serves as guide during plowing.
2. Along each prepared contour line, two furrows are laid. With a distance of 12 cm between hills, two to three seeds are planted per hill which serves as hedgerows. Hedgerow species are *Flemingia macrophylla* (*syn.congestal*), *Desmodium rensonii*, *Calliandra calothyrsus*, *Gliricidia sepium*, *Leucaena diversifolia*, and *L. leucocephala*.
3. The space between rows of nitrogen-fixing trees on which the crops to be planted is called a strip or alley. Cultivation is done on alternate strips (i.e., 2, 4, 6 and so on) to prevent erosion as unplowed strips hold the soil in place.
4. Permanent crops such as coffee, cacao, banana, and others of the same height may be planted when the nitrogen fixing species are sown. Permanent crops are planted every third strip. Tall crops are planted at the bottom of the farm while the short ones are planted at the top.

(continued)

Box 15.1 (continued)

5. Short and medium-term income producing crops (e.g. pineapple, ginger, taro, peanut) are planted between strips of permanent crops.
6. Every 30–45 days, the growing hedgerows are cut to a height of 1.0–1.5 m from the ground with the cut leaves and twigs to be piled on the soil around the crops.
7. Crop rotation is practiced by planting cereals such as corn and upland rice, tubers and other crops where legumes were previously planted.
8. Green terraces are built by piling organic materials such as straw, stalks, twigs, branches and leaves at the base of the rows of nitrogen fixing trees.

6.2 Institutional Efforts

6.2.1 Creation of the Presidential Task Force on El Nino

The Task Force serves as coordinating body for the formulation of comprehensive action plan to mitigate the adverse effects of El Nino. The mitigating measures include cloud-seeding/rain-making operations; Information, education, communication (IEC) campaign; Research and Development; Transfer of appropriate technologies/interventions such as seeds, fertilizers, small farm reservoirs, and small water impounding projects; and Individual shallow tube wells were installed in individual farmer's field as a way to augment irrigation in lowland areas not covered by the national and communal irrigation system.

Approval of the National Integrated Research, Development, and Extension Agenda and Program and Operationalizing the National Soil and Water Resources Research Development Extension (RDE) Network

These initiatives are now implementing research and development projects related to soil and water conservation and management all throughout the country. Through the network linkages, the network RDE agenda are reviewed, formulated and prioritized. Project coordination, implementation and monitoring are likewise harmonized and unified.

6.2.2 Awareness Programs on the Character and Impact of Drought and Land Degradation

This include the conduct of conferences and workshops on "National Awareness on Combating Land Degradation and Mitigating the Effects of Drought in Mindanao" and "Needs Assessment Workshop for Water Resources Management." Another form of the awareness programs was the inclusion of environmental education in the formal education curriculum at all levels and more specifically in soil and water conservation courses in colleges and universities. This is to foster a sense of responsibility for the state of the environment among the students of all ages.

6.2.3 Promotion of Soil and Water Conservation Measures

Intensification of soil and water conservation and drought mitigation measures through innovative approaches in technology promotion activities such as field days, demonstration trials and regular farmers' training. Local and internationally funded projects are and have been implemented in the Philippines with regard to land degradation and drought. One of these projects is the FAO funded "Integrated Management of Salt-Affected Costal Soils in the Philippines" which aims at developing and promoting integrated management techniques for the improvement of salt affected coastal lands in support of the food security program in the country.

6.2.4 Policy/Legislative Efforts

Legislations have been reviewed in order to address underlying factors and crucial issues relevant to combating land degradation and mitigating the effects of drought in the Philippines. These legislations include the Agriculture and Fisheries Modernization Act, Balanced Fertilization Strategy, National Integrated Protected Areas System, and Environmental Impact Assessment.

7 The National Action Plan to Combat Desertification, Land Degradation, Drought, and Poverty (Fy 2004–2010)

Recognizing the worsening problem of land degradation and drought that is closely linked to poverty, the Philippine Senate and House of Representatives jointly ratified the United Nations Convention to Combat Desertification (UNCCD) on February 10, 2000 and final accession came into full force in May 10, 2000.

The membership of the Philippines to the Convention and acknowledgment of the occurrence of desertification is based on the premise that the Philippines along with other ASEAN and tropical countries experience the emerging climatic phenomenon attributed to the increasing recurrence cycle of El Niño and seasonal aridity or seasonal extreme dryness.

The Philippines through its Focal Agency initiated series of consultation workshops and meetings to formulate the Philippine National Action Plan to Combat Desertification, Land Degradation, Drought and Poverty. In 2004, the NAP was finalized and signed by the department secretaries. The Philippine NAP is envisioned to serve as a convergence program among the four departments: Environment and Natural Resources, Agriculture, Agrarian Reform and Science & Technology.

7.1 Scope and Coverage

- The NAP emphasizes the critical value of water in sustaining land productivity
- The NAP provides conscious effort to ensure both quality and quantity of water resources and how they impact on the final quality of safe food products.
- The NAP focuses on highly degraded lands and critical watershed areas located in vulnerable areas. The vulnerable areas are generally areas under Type I climate, which has distinct wet and dry seasons; moderately degraded areas under Type III climate and selected El Niño/Drought prone provinces under Type II and Type IV climate.

7.2 Program Components and Proposed Action Programs

The formulation of the National Action Plan is designed to provide clear understanding of the need for harmonizing actions of local communities and government units and make them aware that managing watershed would require sharing of responsibilities in protecting the trans-boundary river systems, the primary source of freshwater, that cuts across more than one province and municipality as they drain towards the sea.

There are five program components identified under the Philippine NAP (Table 15.5).

8 Government Response to Problems of Land Degradation and Loss

Assessment of Land Degradation at the National level by the Bureau of Soil and Water Management (BSWM) is on-going. The national level data represents several decades of BSWM efforts to assess the state of land degradation in the country. It took more than 30 years to complete its soil resources assessment of the country. Currently, updated land degradation assessments are done at project levels, e.g. SAFDZ-CLUP integration, various watershed projects such as those collaborative with JICA and ACIAR.

A major output of the third JICA-BSWM technical cooperation (2001–2005) was the development of the Agricultural Resources Information System (ARIS). The ARIS integrates the earlier completed Soil Information System (SIS) and the Land Resources Information System (LARIS). The ARIS framework consists of data, query, and model subsystems. Nowadays, to update its data, it does not need to resort to direct field survey methodology again. There are now GIS and remote sensing technologies that BSWM uses. A sample land degradation assessment at local level: Inabanga, Bohol Watershed (completed BSWM-ACIAR project) using

Table 15.5 Scope and coverage of the Philippines National Action Plan (NAP)

Program components	National implementing agency	Schedule of implementation (years)
Land and water technology development		
I. Sustainable agriculture and marginal uplands development		
Case study assessment and mitigation measures against the desertification processes in the oldest irrigation system in Central Luzon	DA	3
Arresting the soil nutrient depletion and water pollution of the strategic zones of agriculture located in seasonally arid areas	DA/DOST	5
Precision agriculture: towards sustaining optimal productivity of rice and corn in the Philippines (in collaboration with FAO)	DA	5
II. Integrated ecosystems management		
Promotion and development of community-based wilderness agriculture for improvement of forest productivity and rehabilitation	DENR/DA	5
Local governance and community initiatives		
I. Sustainable agriculture and marginal uplands development		
Promoting community-LGU partnerships in managing karst water in small island provinces	DAR/DA	5
Conservation farming villages toward sustainable management of sloping lands	DOST	5
Establishment of small water retention structures for upland agriculture and agrarian reform community development	DAR/DA	5
Enhancement of home gardens for food and wood sufficiency and genetic diversity	DOST/DA	1
Farmer experts and farmers participatory learning center	DAR/DA/DOST	5
II. Integrated ecosystems management		
Local governance-community partnership in managing degraded and critical multiple watersheds: case studies in mindanao and luzon transboundary river systems	DENR/DA	5
Data base development and harmonization		
Village-level GIS landscape grid approach for integrated land and water resources database and information development	DA	3
Information, education and communication		
Support to the development and publication of knowledge products and tri-media materials	DA/DAR/DENR/DOST	2
Compendium of community-defined useful plants, herbs, and wildlife and their niches, habitat and distribution		1
Enabling policy development		
Raw water valuation, trading and incentives for water systems	NEDA-PIDS (for negotiation)	1

GIS-Based Land and Water Resources Evaluation (Rodelio B. Carating, personal communication). The outputs were digital map products suitable for planners, policy makers and land users:– administrative map, watershed, soils, soil series, soil depth, land use, dominant land cover, slope, erosion, forestry suitability, crop suitability (oil palm, grassland, and land degradation hot spots).

9 Conclusion

Compared to arid and semi-arid areas, the state of land degradation in the Philippines is not as bad; nevertheless a cause for alarm considering its extent and impact on food security. There are over 33 million Filipinos affected by land degradation. The total degraded land is estimated at 132,275 km^2.

The Philippines has indeed become increasingly vulnerable to drought, desertification and land degradation brought about by many contributing factors, foremost is the increasing recurrence of dry spell and alternating incidence of El Nino and La Nina as well as poor management of land, freshwater and water resources. Combating desertification, land degradation, drought and poverty is an enormous task that would require significant amount of resources and effort not only from one agency of the government but more so from the private sector. The development and implementation of the Philippine NAP is a significant step to address these pressing problems as it will serve as a comprehensive and focused policy instrument that will provide the platform of convergence in policies and programs of the four umbrella agencies in the Philippines, namely the Department of Agriculture, the Department of Agrarian Reform, the Department of Environment and Natural Resources, and the Department of Science and Technology, in combating desertification, land degradation, rehabilitation of degraded lands and preservation of threatened ecosystem with a view to alleviate poverty in degraded, seasonally arid and drought vulnerable areas in the country.

The Philippine National Action Plan to combat desertification and land degradation was revised in 2009 to conform to UNCCD format. There is a need to mobilize the Filipino scientific community for an integrated program for methods, standards, data collection, research network, assessment and monitoring of land degradation, including some socio-economic instruments. There is need to set up an inter-agency task force to work together to come up with Philippine Land System Map. A regular updating of the map is important.

Acknowledgements This chapter contains excerpts from the National Country Report on the UNCCCD Implementation (Philippines) and The Philippine National Action Plan to Combat Desertification, Land Degradation, Drought and Poverty and draws up on the report of Silvino Q. Tejada and Kim Tae-eun (2011) and the report of Rodelio B. Carating, Senior Science Research Specialist Bureau of Soils and Water Management on the State of Land Degradation in Philippines, prepared for UNCCD.

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Chapter 16
Managing Arid Areas and Sand Dunes in Sri Lanka

R.P.M. Weerasinghe

Synopsis This chapter analyzes the land degradation situation in Sri Lanka. It reviews the principal causes of land degradation and the response of government. These responses include legislative reform, administrative and institutional restructuring and implementation of projects to rehabilitate degraded lands.

Key Points

- Sri Lanka was once a heavily forested island. Over the past century its closed canopy forest cover has dwindled rapidly to less than 23 %. In the 1900s it was reported that the forest cover is near 90 % of the total land. Historically, much of the loss was attributed to creation of plantations of tea, rubber, coconut and other crops during colonial times. Recently, settlement schemes to provide livelihood of landless poor, slash and burn for agriculture, encroachment for cultivation, village expansion due to population growth, forest fire and other development activities have contributed to the decline of the island's natural forest cover. Deforestation on steep slopes of watersheds and removal of grass and other protective cover both in the wet zone and in the *slash and burn* cultivation areas of the dry zone leads to severe soil erosion.
- Growing pressure is being placed by people on the land resources. This has caused increasing land degradation which remains a critical constraint on sustainable development of the land resources of the country The man:land ratio is about 0.36 ha, though net per caput land availability is only about 0.15 ha. The remaining 0.21 ha per person is not readily available, because it is either designated for conservation or has topographical or ecological constraints. Approximately 35 % of the country is under agricultural usage and about 31 %

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under forest or wildlife conservation areas. The remaining 34 % is under tea cultivation, pasture, patana grass (*Chrysopogon zeylanicus*) and urban uses.

- A concerted effort is now being made to formulate land use policies and a land use plan. Many organizations in Sri Lanka are responsible for guiding land use related enterprises. The major responsibility lies with the Ministry of Lands, Irrigation and Mahaweli Development, which includes decisions on state lands not already allocated to other institutions. The Land Commission, Forest Department, Department of Wildlife, and Irrigation Department are the major departments under this ministry dealing with land matters. The Soil Conservation Division of the Department of Agriculture is the authority for implementing the provisions of the Soil Conservation Act. The Ministry of Plantation Industries is responsible for the development and control of plantation agriculture in the private sector. The Rubber Control Department and Tea Commissioner's Division are involved in new plantations and re-plantation schemes and have a control on conservation measures The Ministry of Coconut Industries handles enterprises related to coconut cultivation and industry.

Keywords Desertification • Biodiversity • Salinization • Sri Lanka • Climate • Land allocation. Slash and burn • Coastal dunes • Uplands • Tea • Forestry • Deforestation • Biodiversity • *Chena* • *Patana* grass • Rubber

1 Introduction

The Democratic Socialist Republic of Sri Lanka (formerly Ceylon) is an island in the Indian Ocean off the south-eastern coast of India, a member of the Commonwealth of Nations (Fig. 16.1). Sri Lanka is separated from India by the Polk Strait and Gulf of Mannār. Lying between the two nations is a chain of tiny islands known as Adam's Bridge. The greatest length from north to south is 440 km (270 miles); the greatest width is 220 km (about 140 miles) and has about 1,340 km (827 miles) long coastline. The total area of Sri Lanka is 65,610 km^2 (25,332 sq miles). The administrative capital of Sri Lanka is Sri Jayawardenepura (Kotte), and Colombo is the commercial capital and largest city.

An outstanding feature of the topography of Sri Lanka is a mountainous mass in the south central part of the country, the highest point of which is the peak of Pidurutalagala (2,524 m/8,281 ft). In the upland area are two plateaus, Nuwara Eliya and Horton Plains, which are major centers of commercial tea plantations. The plateaus are noted for their cool, healthful climate. North of the mountains, and extending south, is an arid and gently rolling plain known as the dry zone.

The population of Sri Lanka (2011 estimate) is 21,401,300, yielding an overall population density of 316 persons per km^2.

Fig. 16.1 Sri Lanka is a tropical country with a land area of 65,610 km^2

2 Climatic Zoning

The land of Sri Lanka can be divided into seven climatic zones that correspond to annual rainfall. In other case according to rainfall and type of vegetation it can be divided in to four main zones; the wet zone, dry zone, intermediate zone and arid zone. The central highlands include numerous mountains, plateaus, and valleys.

The natural vegetation of Sri Lanka varies according to climatic zone and elevation. Dense evergreen rain forests are found in the southwestern lowlands. Trees include *Dipterocarpus zeylanicus* and many varieties flowering trees, including *Doona* species. In the central highlands, montane evergreen forests are interspersed with grasslands. The drier evergreen forests in the north and east contain trees such as Ceylon ebony *Diospyros ebenum* and satinwood *Chloroxylon swietenia*. In the arid zone thorn forests and drought-resistant shrubs prevail in the driest areas. Along the coast, mangrove forests border lagoons and river estuaries.

3 Land Use Patterns and Trends

Sri Lanka is a tropical country with a land area of 65,610 km^2. The land-use pattern of Sri Lanka comprises an upland plantation sector growing mainly tea and rubber, as well as a large domestic food production sector with rice being the main food crop. In the hill-country and mid-country of Sri Lanka degradation has caused a

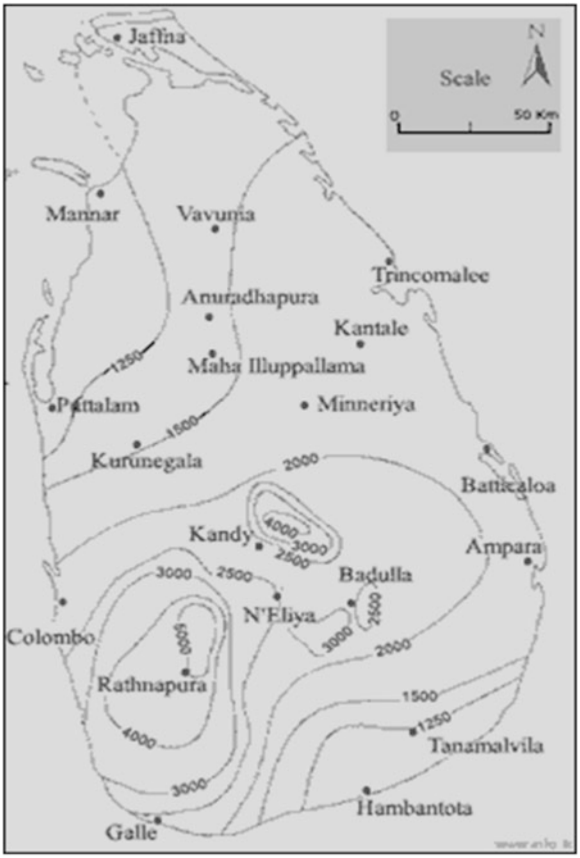

Fig. 16.2 Rainfall varies from very high >5,000 mm annually to low <1,250 mm in the so-called dry zone

10 % contraction in the land area planted to tea while 25 % of the land previously planted to rubber has become uneconomic for growing rubber due to soil erosion. Silting of reservoirs and canals caused by upland soil erosion imposes substantial costs and is a serious threat to food production and power supplies.

Sri Lanka enjoys plentiful rainfall, but some parts of the island face acute water scarcity. Increased demand for water from the expanding industrial sector, rapid urbanization and the consequent generation of waste, industrial effluents, increasing use of agricultural chemicals, fertilizer, herbicides, and increasing salinity in irrigated paddy lands are causing water pollution.

Although Sri Lanka does not have any desert areas as defined by the UNCCD, some parts of the country experience serious droughts and land degradation. The processes associated with desertification, defined as loss of productivity of previously functioning non-desert ecosystems (See Chap. 1) may occur in the drier zones of Sri Lanka (Fig. 16.2) in the near future. This would be due to accelerated land degradation caused by human activities such as deforestation, unplanned agricultural expansion, and overgrazing. In the inland regions desertification remains a significant threat to peoples' livelihood and land degradation is one of the major challenges facing the people in promoting environmental protection and sustainable development. But coastal areas are also under threat from mobile sand dunes (see below).

Sri Lanka was once a heavily forested island. Over the past century its closed canopy forest cover has dwindled rapidly to less than 23 %. In the 1900s it was reported that the forest cover is near 90 % of the total land. Historically, much of the loss was attributed to creation of plantations of tea, rubber, coconut and other crops during colonial times. Recently, settlement schemes to provide livelihood of landless poor, slash and burn for agriculture, encroachment for cultivation, village expansion due to population growth, forest fire and other development activities have contributed to the decline of island's natural forest cover.

Deforestation on steep slopes of watersheds and removal of grass and other protective cover both in the wet zone and in the *slash and burn* cultivation areas of the dry zone leads to severe soil erosion. Head-ward gully erosion in the plains of the dry zone is substantial. River bank erosion is confined to flood plain areas due to undercutting during floods. Overgrazing and trampling by cattle promote soil erosion in the dry zone. Landslides add further to erosion, especially on cultivated slopes in the hill country. Deforestation has caused the natural dense canopy forest cover in the country to dwindle from 80 % at the turn of the 20th century, to less than 20 % by 2002. Forests have been cleared by government agencies for agriculture, settlement schemes and other development projects. They have been cleared illegally for shifting cultivation and for homesteads. Irregular agricultural activities, deforestation and setting fire to forests have also contributed to this situation. Deforestation appears to be continuing despite efforts at controlling the problem and impacts adversely on the environment, the welfare of the rural sector, agriculture and related sectors and the overall economy of Sri Lanka. Forest conservation and afforestation is at a low level compared to the rate of forest destruction.

Sri Lanka is one of the smallest but biologically most diverse countries in Asia. Consequently, it is recognized as a biodiversity hotspot of global and national importance. Its varied topography and tropical island conditions have given rise to extremely high levels of biological diversity and endemism, particularly in the natural forests. More than 3,650 species of floral plants, 300 species of pteridophytes, about 400 birds, almost 10 animals and more than 160 reptiles can be found in Sri Lanka and 26 % of flowering plants, 76 % of land snails, 60 % of amphibians and 49 % of reptiles are endemic to Sri Lanka. The Sinharaja Forest Reserve, which protects the largest remaining stand of primary rain forest on the island, was declared a World Heritage Site in 1988. The government has ratified international environmental agreements pertaining to climate change, desertification endangered species, environmental modification, hazardous wastes, law of the sea, ozone layer protection, and wetlands. Eutrophication of water bodies due to excess plant nutrition by soil erosion increased the growth rate of aquatic invasive plants such as *Salvinia* and *Eichornia* ("Japan Jabara" – a species of Water Hyacinth).

In Sri Lanka, there are two dry zones found in south-east area of Hambanthota District and north-West area of Mannarama and Puttalama Districts. Both dry zones are situated near the coastal zone. The altitude of the area is 0–100 m and the wet season of 4–5 month peaks in September-November (the north-east monsoon). The temperature is nearly 35 °C. The cause of aridity in this areas can identified as

- Low annual rainfall less than 1,200 mm/year.
- Deforestation
- Salinization
- Overgrazing.
- Over cultivation
- "Chena type" shifting cultivation and illicit human activities
- In the arid zone; thorn forests and drought-resistant shrubs are found.

The characteristics of those forests are: Short (about 2–5 m high) thorny bushes are present and drought resistant through a number of adaptations relating to morphology, physiology and crop architecture.

The prominent species of this area are *Zizyphus oenoplia* – Heen eraminia (sinhala), *Carissa carandas* – Maha karanda (sinhala), *Bauhinia racemosa* – Maila (sinhala), *Dichrostachys cinerea* – Andara (sinhala), *Opuntia dillenii* – Pathok (sinhala), *Euphorbia antiquorum* – Daluk (sinhala), *Acacia leucopholea* – Katu andara (sinhala), *Prosopis juliflora* – Kalapu andara (sinhala)

The coastal area has the highest population pressures and contains a number of critical habitats. Coral mining, clearing of coastal vegetation, clearing of mangroves, sand mining in beaches and coastal dunes, haphazard construction, and the dumping of waste have led to pollution, coastal erosion and degradation of habitats. These critical habitats are small and highly vulnerable to exploitation and degradation, and need to be managed sustainably. The *Coast Conservation Act* of 1981 provides for the management of the coastal zone and the appointment of a director (Coast Conservation) for the implementation of the Act and to formulate and executes schemes for coast conservation.

3.1 Population, Employment, Land Use – The Eternal Triangle

Growing pressure is being placed by people on the land resources. This has caused increasing land degradation which remains a critical constraint on sustainable development of the land resources of the country The man:land ratio is about 0.36 ha, though net per caput land availability is only about 0.15 ha. The remaining 0.21 ha per person is not readily available, because it is either designated for conservation or has topographical or ecological constraints. Approximately 35 % of the country is under agricultural usage and about 31 % under forest or wildlife conservation areas. The remaining 34 % is under tea cultivation, pasture, patana grass (*Chrysopogon zeylanicus*) and urban uses (Fig. 16.3).

Fig. 16.3 There are extensive areas, especially in the Horton Plains area that are covered with patana grass (*Chrysopogon zeylandicus*)

Current evidence indicates that increasing areas are subject to land degradation and poor management, lessening the land available for agricultural uses. Apart from areas under shifting cultivation, it is estimated that 46 % of the agricultural land is affected by water erosion and 61 % by declining soil fertility. Large losses of soil and declining soil fertility continue to result in reduced crop yields, increased production costs and lower incomes for many land users.

The total extent of agricultural land is 31 % with a per capita land availability of 0.38 ha but agricultural land per capita is 0.26 ha which is among the lowest in Asia and which is subjected to fragmentation and eventual overexploitation of land. As populations grow, farmers are forced to cultivate smaller and smaller plots, where the soil eventually becomes depleted, or they expand onto marginal lands – fragile hillsides, semi-arid areas, cleared forestland. Low-intensity multi-crop agricultural regimes which supported natural eco-systems and preserved soil fertility have been largely replaced by plantatin agriculture, reducing national forest cover to 22 % by 2002. Large quantities of pesticides and herbicides are used in farmlands close to pristine forest reserves; their impact on non-target organisms and on the environment needs urgently to be assessed, and mitigatory actions taken accordingly. There is doubt about whether they can be repaired once these lands become damaged.

According to FAO estimates the extent of degraded arable land is about 10.8 % (Report on Land Use-1998) About 10 % of the tea land and 25 % of the rubber land have been abandoned due to reduced productivity caused by soil erosion (Griggs 1998). The farming communities, as well as the policy planners, have not adequately appreciated the "real" cost of erosion to the economy because its adverse impacts are not immediately manifest. The adverse impacts of "*Chena*" or "slash and burn farming" on the ecology and environment were highlighted in the Land Commission Report of 1987. They include changes in microclimate, soil erosion, and destruction of natural vegetative cycle and loss of forest reserves. With the diminishing land resource, "slash and burn" farming has been transformed into a system of "Unirrigated Highland Crop Farming" (UHCF) which is people's adaptation to nature as a strategy for survival. Planting/sowing in UHCF systems is either with the "drought ending rain" or soon thereafter, in mixed stands. This plant-crop mixture includes a variety of food crops, cash-cum-food crops, drought resistant as well as moisture loving crops of short and long durations of growth. The field research has shown that UHCF farmers undertake such soil conservation practices as construction of earth contour ridges, contour drains, terraces and retaining walls and growing hardy grasses on the contour of ridges.

Employment opportunities in the rural sector did not expand in proportion to increasing population. Consequently the poorer groups are forced to depend on the diminishing land resource base. Successive governments have therefore been compelled to create employment opportunities by opening up forest and reserve land. The need to rationalize use of land in Sri Lanka has been realized for quite some time. Protective measures had been attempted mainly through enactments which lay down conditions for the protection of land and soil. An institutional framework has also been established to promote and implement such conservation measures but the implementation has not happened (Box 16.1).

Box 16.1: Government Agencies Involved in Dealing with Land Related Issues in Sri Lanka

There are eight key government institutions involved with land related activities in Sri Lanka. They include four agencies of the Ministry of Agriculture and Lands (MAL) and four agencies outside the MAL, as follows:

Survey Department. Responsible for land surveying and mapping of country. General work program includes contour surveys for irrigation and other purposes, block and topographical preliminary plan surveys and settlement demarcation surveys, town surveys, forest surveys, sporadic surveys including acquisitions, aerial surveys.

Land Commissioner's Department. Responsible for the protection, development, management and distribution of state-owned land, including the distribution of lands under various schemes, issue of permits, grants and leases under principal acts and laws relevant to administration of lands. Land distribution programs predominate and concern relieving

(continued)

Box 16.1 (continued)

landlessness and unemployment. The Department is also involved with the alienation of state land.

Natural Resources Management Center (***NRMC***)***, of the Department of Agriculture.*** The center optimizes land and water resources use on a scientific basis for excellence in agriculture.

To achieve this the NRMC is engaged in:

- development and dissemination of land conservation and water management techniques for sustainable agriculture;
- development and maintenance of a database on land and water resources;
- soil survey, land suitability evaluation and land use planning;
- technical assistance for watershed management, land use planning and farm development;
- implementation of the Soil Conservation Act of 1951, amended in 1996 and training trainers in soil and water conservation.

Land Use Policy Planning Division (***LUPPD***)**.** This Division of the Ministry of Agriculture and Lands has the responsibility for introducing systematic land use planning throughout the country, based on scientific criteria. Its objective is to ensure the utilization of natural resources to the maximum benefit of society, by the formulation of land use policies and the preparation of land use plans. These should allocate land resources among competing users on a rational basis, so that optimal and sustainable land uses are maintained.

Strategies adopted by the LUPPD in achieving these objectives include:

- preparation of land use plans at national and sub-national levels;
- preparation of a national land use policy;
- establishment of a land information system and a land data bank;
- conduct training and awareness programs on land use planning for agencies.

The National Land Commission under the LUPPD formulates national policy statements regarding the use of land in the country. To achieve this a Technical Secretariat attached to the Commission is required to evaluate physical and socio-economic factors relevant to natural resources management.

Urban Development Authority (***UDA***)**.** The Authority is expected to promote integrated planning and implementation of economic and physical development of areas declared by the Minister to be Urban Development Areas. In any area declared as an Urban Development Area, the UDA is expected to:

(continued)

Box 16.1 (continued)

- carry out integrated planning and physical development;
- prepare a development plan;
- implement programs of development consistent with integrated planning;
- formulate and implement an urban land use policy;
- develop environmental standards and prepare schemes for environmental improvement.

Upper Mahaweli Environment and Forestry Conservation Division (EFCD). Within the Mahaweli Authority of Sri Lanka, this Division promotes the protection and scientific management of the Upper Mahaweli catchment area, through watershed management methods. The strategy adopted by EFCD is to provide Government institutions, non-governmental organizations (NGOs), private sector agencies, groups and individuals operational in the area with information, technical expertise and initial material inputs so that they can successfully implement watershed conservation measures. The Division operates in three teams:

- Conservation – soil, water, forest conservation activities and techniques, etc.
- Participation – human resources development – awareness, training, mobilization.
- Information – collation of database, analysis and sharing of data – mapping, land use planning, GIS, economics, hydrological monitoring.

Registrar General's Department. The supervision of notaries and verification of stamp duty on deeds, the registration and custody of notarial deeds and other documents affecting property and the preservation of records and issue of copies from such records are responsibilities of this Department.

Law Commission. The Law Commission was established under Act No. 3 of 1969 for the promotion of the reform of the law. The functions of the Commission include keeping under review both substantive and procedural law, with a view to its systematic development and reform, including the codification of the law, the elimination of anomalies, the repeal of obsolete and unnecessary enactments, the reduction of the number of separate enactments and generally the simplification and modernization of the law. The Commission is empowered to receive and consider proposals for the reform of the law.

Civil Society is also increasingly involved in land-related activities, through NGOs, special interest and advocacy groups and community-based organizations. At the local level these groupings are involved in a wide range of activities supporting stakeholders in sustainable management of the land resources on which they depend.

4 Main Forms of Land Degradation

Environmentalists have predicted that Sri Lanka will face severe drought and desertification within the next few years. Drying up of water springs, soil erosion, potential for landslides, loss of soil fertility will be among the harmful effects of this. Climate change would only make matters worse. There is now recognition that the magnitude of the problem caused by land degradation is much greater than previously realized and also that there are multiple benefits of implementing the Convention to Combat Desertification, Sri Lanka signed the convention in 1995 and ratified it on 14th October 1998 Sri Lanka has aligned itself with other member countries of the Convention to prevent land degradation and combat Desertification. The Minister of Forestry and Environment (MoFE), is host to the national focal point of the implementation of UNCCD and Sri Lanka is combating desertification in line with its National Action Program (NAP) as required by the Convention to Combat Desertification (CCD).

Sri Lanka being predominantly an agricultural country, land erosion is rampant where soil conservation is not practiced. Pronounced erosion is also seen along major roads and forest clearings for settlements where the erosion problem has not been adequately addressed. Gem mining activities carried out in river beds, banks and upland areas lead directly to soil erosion.

The main forms of land degradation are soil erosion; water-logging, pesticide accumulation in the soil, groundwater and surface water bodies; land degradation due to extraction of raw materials for the ceramic and cement industry; industrial pollutants discharged into agricultural land, gem stone mining, sand mining, brick and tile clay extraction. No detailed survey has been carried out to quantify land degradation in Sri Lanka. Technologies have been proposed largely in the agricultural sector. In Sri Lanka terracing and bunding are the orthodox methods of practical soil conservation in both dry and wet zones (Fig. 16.4). Windbreaks have been established in certain areas. There is no proper mechanism to implement the remedial measures proposed by the technocrats (Box 16.1) Study and research is carried out in the public sector. There are few scientists and a lack of both laboratory and field facilities. Detailed data for proper scientific land use planning is lacking. As some of the processes and factors affecting land use change with time, a continuous program of or regular updating of data is necessary. Although most data for planning at a national scale is available data on regional scale is scarce. Data on soil, land and land use has been generated in the Land Use Division of the Irrigation Department and is available only for four districts out of 22. There is no proper infrastructure for land use planning. No organization has overall controlling authority. There are many agencies with some responsibility (Box 16.1). The scientific task of land use planning as to be conducted by a scientific department of land use planning but there is a great deficiency of resources and trained personnel (Table 16.1).

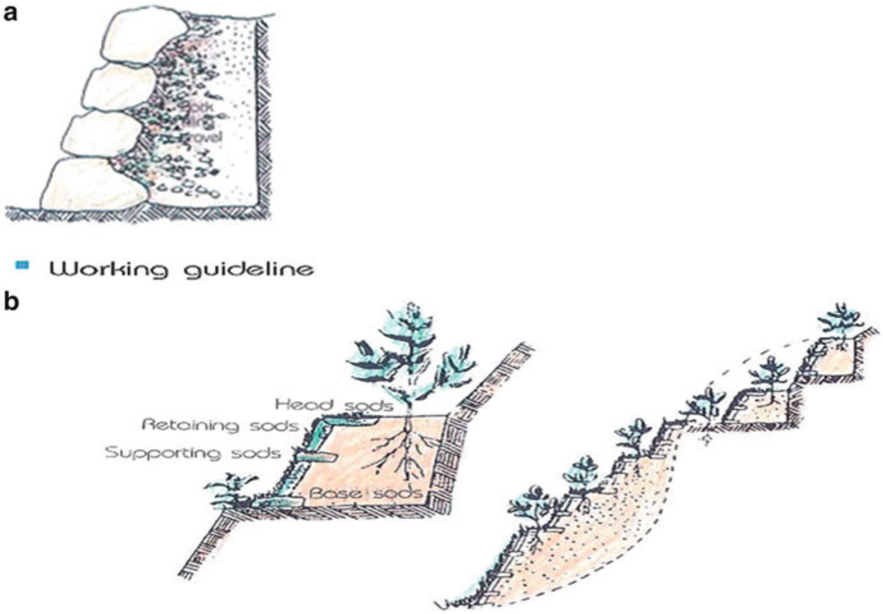

Fig. 16.4 Soil erosion control works like these are being used to (**a**) control water flow and (**b**) create terraces

Table 16.1 Extent of each soil erosion hazard class within the Central Province of Sri Lanka

	Nuwaraeliya		Kandy		Matale	
Soil erosion hazard	Extent (ha)	%	Extent (ha)	%	Extent (ha)	%
Low	49,610	29	46,792	25	94,500	47
Moderate	53,635	31	54,618	29	75,929	37.4
High	28,185	17	36,171	19	12,450	6.2
Very high	32,890	19	47,790	25	18,900	9.3
Extremely high	6,255	4	3,790	2	160	0.1
Total	170,575	100	189,161	100	201,939	100

4.1 Major Causes for Land Degradation

4.1.1 Natural Resource Base Related

- Geomorphologic conditions and rainfall characteristics conducive to severe land degradation in the form of soil erosion

4.1.2 Human Related

- High dependency on land for livelihoods
- High demand for agricultural lands under increasing population density, which leads to encroachment of forests and marginal lands

- Farmers who do not see the short term benefits of implementing soil conservation and who have no concern for soil conservation
- Inadequate attention on soil conservation particularly in annual cropping
- Inadequate legislation or non-implementation of available legislation towards proper use of lands
- Land fragmentation, ownership and unfavorable tenancy condition (land tenure issues)
- Lack of proper land use policies
- Ad hoc planning of infrastructure development or lack of holistic approach
- Lack of efficiency in plan implementation
- Decision makers/Politicians still use land allocation among poor unemployed citizens as a means of employment generation
- Lack of incentives for proper land use
- Lack of collaboration in related institutes, departments etc.

In Sri Lanka, the major contributors to land degradation are (i) soil erosion and (ii) soil fertility degradation. Over exploitation of ground water, salinization, water logging and water pollution are also becoming important contribution to land degradation. According to the Global Assessment of soil degradation (GLASOD 1990), about 50 % of land is degraded. The area affected by soil fertility decline is 61 % of the total agricultural land.

4.2 Soil Erosion

It has been estimated that nearly one-third of the land in the country is prone to soil erosion; the proportion eroded ranging from less than 10 % in some districts to over 50 % in others. Much of the erosion has been taking place in the hill country, the problem being given over to the cultivation of highly erosive temporary crops such as vegetables, potatoes, tobacco and seedling tea. The highest figures of soil loss in mid country wet zone and intermediate zone are 40 tons/ha/year for old seed tea plantation and 70 tons/ha/year for tobacco cultivation with no soil conservation measures adopted (Fig. 16.5).

A clear pattern of soil erosion has been observed in the Hill Country, mid country and the low country. Comparative studies of erosion by zones have shown that mid country to be the most vulnerable to erosion. Soil loss by erosion varies between regions and ranges from 140 tonnes per ha each year (t/ha/yr) in the low country to over 1,020 t/ha/yr in the mid country. High country losses are 412 t/ha/yr. According to the National Report on Desertification/Land Degradation in Sri Lanka (2000), the on-site and offsite costs of soil erosion have been estimated in recent studies. Some of the estimates are: (A) Onsite cost – (1) Value of loss of productivity – Rs. 3,529 ha/yr; (2) Value of loss of nutrients – Rs. 5,068 ha/yr; (3) Estimated cost due to nutrient loss in Upper Mahaweli watershed – Rs. 953.0 million (B) Offsite cost – (1) Based on value of loss of productivity – Rs. 3,952 ha/yr; (2) Based on value of loss of nutrient – Rs. 5,481 ha/yr; (3) Estimated loss in hydro-power production and irrigation from the Upper Mahaweli Watershed – Rs. 15.0 million per annum.

Fig. 16.5 Erosion damages crops and makes areas of land less productive. Gullying in a cropped field can expose of bare rocks

4.3 Soil Fertility Decline

Soil fertility decline is caused by soil erosion and poor cropping practices and nearly 1.6 Mha. of agricultural land in Sri Lanka is affected. Decline in crop yields have been reported during the last two decades due to soil fertility loss and other forms of degradation such as structural decline. The loss of 1 cm of top soil cover of tea and rubber lands is associated with a decline in yield of 44 and 174 kg/ha/yr respectively.

The susceptibility to erosion (erosion hazard) has been assessed and map prepared (Fig. 16.6) as a guide to land use planning agencies and those agencies in charge of erosion control.

5 Control of Land Degradation

A major role for government is to create an enabling environment so that efforts to control land degradation can proceed in an efficient and effective way. Typically, government enact legislation and devise administrative regulations that are aimed at providing constraints to developments that endanger the land and water resources its biodiversity.

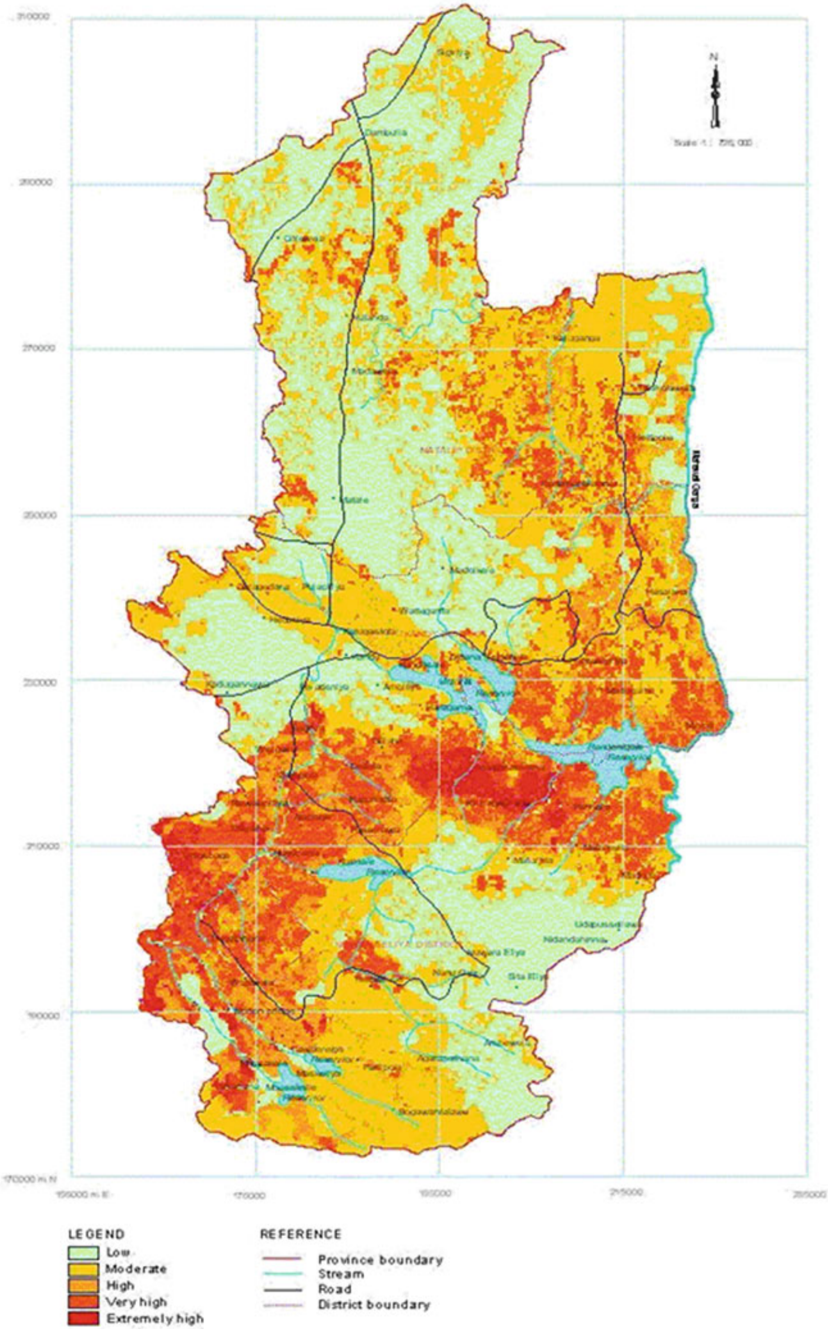

Fig. 16.6 Soil erosion hazard map of central region of Sri Lanka. The severity is expressed as low (*pale gray*), moderate, high, very high and severe (*red*)

5.1 Response by Government

The concern of the Government regarding this problem is reflected in policy initiatives taken, enactment of legislation, the formulation of plans and strategies and the establishment of institutions to arrest soil erosion. The approach to soil conservation is evidenced in the policies spelt out for management of natural resources in the National Land Use Policy, Forestry Sector Master Plan and the Agricultural policy.

There are several main agencies involved in dealing with land related issues in Sri Lanka and their mandates overlap to a certain extent (see Box 16.1).

Land degradation is one of the most acute problems with it being manifested in the following manner: decline of arable land, decrease in land fertility and agricultural productivity, loss of irrigation and hydropower generation capacity due to silting of reservoirs and tanks, floods, and landslides. Biodiversity is being increasingly eroded as a result of excessive habitat fragmentation and destruction of ecosystems due to deforestation, filling of wetlands, over exploitation of biological resources such as timber for commercial purposes, destruction of coral reefs, and the pollution of inland and coastal waters.

Soil Conservation Act of Sri Lanka first came into effect in 1951 as Act No. 25 with the objective of conserving soil resource, prevention or mitigation of soil erosion and protection of land against floods and droughts. It was amended in 1996 by Soil Conservation (Amendment) Act No. 24 of 1996 to include wider scope thus addressing land degradation as well. The Department of Agriculture has been the implementing agency for the Soil Conservation Act from its inception. Lack of adequate institutional backing for effective implementation have been a problem until recent times. The Soil Conservation Act of 1951 was subsumed by new arrangements following the report of the Presidential commission.

The task force appointed by the President of Sri Lanka in 1982 formulated a national conservation strategy that incorporated the conservation o f land and soil. It recommended that the earlier *Soil Conservation Act* be replaced by a more comprehensive *Land Use*, *Soil and Water Conservation Act*. It has also recommended the establishment of soil conservation units in other agencies involved with the development and use of land and the importance of incorporating the topic of soil conservation into school curricula. Among NGOs, the Soil Conservation Society was formed to promote the message of soil conservation to the general public. The Central Environmental Authority, along with the formulation of an action plan for the implementation of the recommendations made in the conservation strategy, actively participates in a variety of conservation programs.

A concerted effort is now being made to formulate land use policies and a land use plan. Many organizations in Sri Lanka are responsible for guiding land use related enterprises. The major responsibility lies with the Ministry of Lands, Irrigation and Mahaweli Development, which includes decisions on state lands not already allocated to other institutions. The Land Commission, Forest Department, Department of Wildlife, and Irrigation Department are the major departments under this ministry dealing with land matters. The Soil Conservation Division of the

Fig. 16.7 Tea plantations are important but their establishment has contributed to deforestation

Fig. 16.8 Coconut plantations can provide soil protection

Department of Agriculture is the authority for implementing the provisions of the Soil Conservation Act. The Ministry of Plantation Industries is responsible for the development and control of plantation agriculture in the private sector. The Rubber Control Department and Tea Commissioner's Division are involved in new plantations and re-plantation schemes and have a control on conservation measures The Ministry of Coconut Industries handles enterprises related to coconut cultivation and industry (Figs. 16.7, 16.8, and 16.9).

Fig. 16.9 Rubber plantations occupy uplands. They have replaced native forest

Traditionally soil conservation is the main responsibility of the Ministry of Agriculture (MoA) and only a partial responsibility of the Ministry of Environment and Natural Resources. MoA has been keen to address this problem and several measures such as reforestation, adopt regulatory framework for soil conservation, develop policy framework for combat land degradation under the Convention to Combat Land Degradation and reduce soil and water pollution have been adopted over the past few decades to control the land degradation. However these have only had a limited impact and this is reflected in the spread of settlements into environmentally fragile areas; eroded uplands; low and unreliable crop yields, and other offsite effects of soil erosion such as sedimentation of reservoirs and foods. These trends need to be reversed early; if not, there could be serious economic and social consequences.

Clearly, there are number of policies, strategies and plans prepared by different Ministries, Departments and other Agencies that address various aspects of land degradation in Sri Lanka. They have also introduced environmental safeguards. The Ministry of Industry and Investment Promotion has also prepared policies such as the National Industrial Pollution Reduction Policy and the Industrial Site Selection Policy that also address the land degradation issues. The Department of Agriculture (under the Ministry of Agriculture) has prepared several policies, strategies and plans such as the National Policy Framework – Ministry of Agriculture Lands and Forests-1995, National Land Use Policy (draft) – 2002, National Policy on Agriculture and Livestock-2003, The National Agriculture, Food and Nutrition

Strategy – 1984, that address problems such as the mitigation of soil erosion, improvement of soil fertility and the conservation of soil and water all of which are related to land degradation in the country.

The Department of Agriculture (DOA) in general and the Natural Resources Management Division in particular are heavily involved in addressing land degradation issues. Recommendations pertaining to soil conservation activities and the implementation of agricultural and other relevant policies related to control of land degradation are some of the activities conducted by the DOA in collaboration with other institutions such as Hadabima Authority, Upper Watershed Management Project, Provincial Department of Agriculture, Ministry of Up country Development. These projects use traditional and local technologies to combat land degradation. The Hadabima Authority of Sri Lanka is engaged in various development programs in mid country area. Programs are conducted through a participatory approach. These include soil conservation and watershed management, home garden development, soil rehabilitation and rainwater harvesting in the mid country. The officers of the Authority educate farmers and use traditional as well as available local technologies in controlling soil erosion and the conservation of water in the area. Research institutes such as the Rubber Research Institute and Tea Research Institute adopt measures for the conservation of soil and water in rubber and tea lands. As local technologies, agro forestry systems and ground cover management introduced by the Rubber Research Institute are being used in rubber plantations.

The Department of Forests contributes to the control of soil erosion and conservation of water resources through the use of traditional and/or local technologies partly by implementing activities detailed in the Forestry Master Plan and partly through projects such as the Forest Resource Management Project and the South-West Rain Forest Conservation Project. The Department of Export Agriculture implements a number of programs that are closely linked with soil conservation and the improvement of land productivity.

The Department of Forest is responsible for mitigating the impacts of desertification process mainly in the arid zone of the island in addition to other areas.

Department of Forest has been involved in several ways to achieve this goal. Some of these efforts are as follows:

Protection of forests in the country.

- By educating the people
- By law enforcement
- By enrichment of existing forests
- By afforestation programs
- By local people participation methodologies

Conservation of biodiversity.
Stabilizing sand dunes formed in arid zone areas.
Conservation and stabilization of soil.

Establishment of forest plantations on sensitive areas.
Planting tree belts as windbreaks.

Development of technology to minimize soil erosion, moisture conservation, optimization of fertilizer use efficiency, implementation of productivity improvement programs at field level, promotion of integrated soil fertility management measures, promotion of agroforestry systems and proper management of such systems for optimization of resource utilization, implementation of farmer level programs for crop productivity improvement through soil and moisture conservation, development of an optimum ground cover by filling vacancies etc. are some of the major program areas of the Department of Export Agriculture in relation to the control of soil erosion, moisture conservation and soil fertility improvement through the use of traditional as well as local technologies.

Mahaweli Authority of Sri Lanka (MASL) also contributes in fulfilling the above requirement under the provisions of relevant acts such as the Mahaweli Authority Act, the National Environmental Act, the Soil Conservation Act and policies such as the National Watershed Management Policy even though it does not have a mandate to implement activities under CCD. MASL uses traditional and/or local technologies i.e. biological, chemical and agronomical soil conservation measures and cropping systems to control soil erosion and to conserve water resources especially in the up and mid country areas of Sri Lanka. In the past MASL has obtained the services of international experts to address the issues such as soil erosion, conservation of water resources, rehabilitation of degraded lands in the Mahaweli watershed areas.

The Alternative Energy Division of Ministry of Science and Technology is involved in the promotion of alternative energy technologies and the establishment of sustainable energy plantations on marginal and degraded lands. The Division has also proposed the utilization of agro-based residues for methane production to be used as automobile fuel. Through these activities, the Division contributes to the improvement of the livelihoods of rural communities and the rehabilitation of degraded lands.

6 Coastal Dunes

Dunes are windblown accumulations of sand that remain unstable unless covered by vegetation. Extensive dune systems have developed between Mullathivu and Point Pedro, Between Elephant Pass and Chavakachcheri, across Mannar Island, between Ambakandawila and Kalpitiya and between Hambanthota and Sangamankanda point. Forest Department of Sri Lanka planted those coastal areas with ***Casuarina equisetifolia*** (Kasa in Sinhala) for protection of coast and for stabilizing the dunes, and also to prevent saline wind blows from seaside (Fig. 16.10).

Fig. 16.10 *Casuarina equisetifolia* plantations in Hambanthota District coast line

6.1 Functions and Value of Dunes

Distinctive communities of plants inhabit the beach/dune systems. This vegetation promotes accretion, binds the sediments, provides moderate protection against costal erosion, and helps bar the transport of sand by wind. When Tsunami occurs e.g. 26th December 2004, the sand dunes protect lot of lands in this area. The prominent species of this area are: *Ipomoea pescaprea* – Binthamburu (sinhala), *Pandanas tectorius* – Moodu Keyya (sinhala), *Spinifex littoreus* – Maha rawana rewla (sinhala), *Salvadora persica* – malittan (sinhala).

6.2 Sand Stabilization Efforts

Destabilized coastal dunes are a special problem faced by a few countries. Techniques and approaches have been devised to combat shifting dunes and some of them have been trialled in Sri Lanka. Planting wind breaks of salt tolerant trees like *Casuarina* (see Fig. 16.10) is one of them.

Several well proven techniques were used to fix the sand. For dunes, the method involved sand-trapping (Fig. 16.11) and for sand plains, a checkerboard layout (Fig. 16.12) was used. Trees were planted and the area became stabilized.

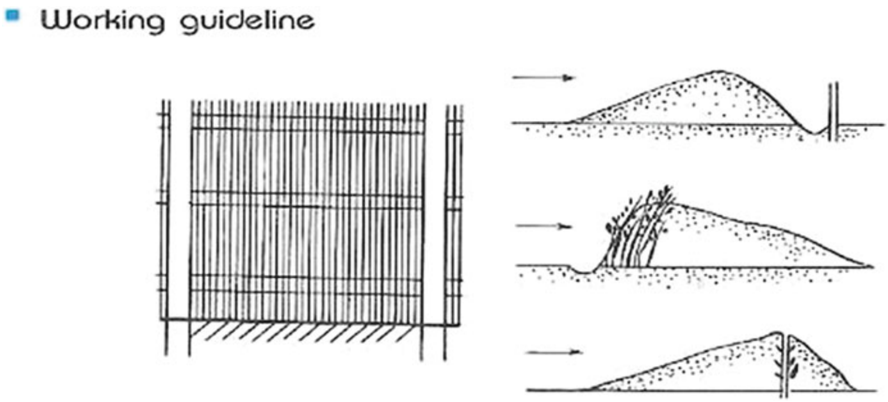

Fig. 16.11 Sand dune stabilization by erection of semi-permeable (slatted) fence to change wind flow patterns and reshape dunes

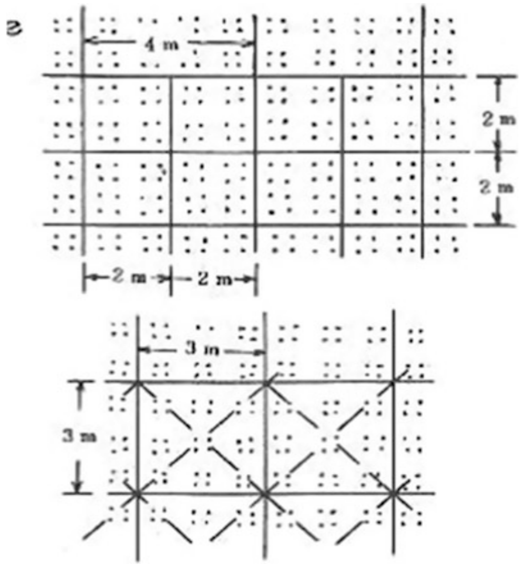

Fig. 16.12 Layout of slatted fences to stabilize sand plains Fences are about 6–80 cm high

6.3 Successful Projects

There are successful community-based projects that attempt to arrest and reverse land degradation and protect biodiversity**.** Sloping land has been the focus of some of them. The donor community has funded projects e.g. Watershed Management (ADB), and Watershed Protection in Selected Micro Catchments of Mahaweli (World Bank).

The other projects/programs related to soil conservation are:

- Re-forestation and Watershed Management Project (1980)
- Community Forestry Project (1982)
- Land Use Policy Planning Project (1983)
- Upper Mahaweli Watershed Management Project (1987)
- Forest Land Use Mapping Project (1989)
- Landslide Hazard Mapping Project (1990)
- Shared Control Of Natural Resources Project (1992)
- Optimal Land Use in Sri Lanka with particular application to Land Degradation in Plantation Industries (1994)
- Environmental Action I Project (1995)
- Upper Watershed Management Project (1997)
- Integrated Rural Development Programs (1982).

These projects and programs generated new policies and concepts of soil conservation, including the value of public participation and co-management of natural resources with the community. The government is now aware that soil erosion cannot be contained through simple technological interventions and those larger socio-economic factors that impinge on soil erosion need to be addressed. Strong emphasis has been laid on new conservation measures and techniques developed both by the Department of Agriculture and private researchers such as “Conservation Farming” and “Sloping Agricultural Land Technology (SALT)”. NGO and bilateral donors also assist (Box 16.2).

Box 16.2: Community Action Program to Reduce Land Degradation and Conserve Biodiversity in Maguru River Basin by Organization for Aquatic Resources Management – GEF Small Grants project

This project will reduce land degradation and conserve biodiversity in Boralugoda (Maguru River). Maguru River has the highest freshwater fish species diversity in Sri Lanka. In this river, there are 47 species of fresh water fish and out of that 20 species are endemic to Sri Lanka. Immediate conservation and management measures need to be taken to preserve this vulnerable ecosystem.

The area has also suffered from the harmful effects of tea cultivation and road construction, which has led to severe soil erosion. Lack of awareness on proper land management have contributed to this as well. Therefore, the Organization for Aquatic Resources Management (OARM) intends to conserve the fish population in Maguru River, reduce land degradation in the Boralugoda area, conserve local biodiversity and provide sustainable livelihoods for local community members.

To fulfill these objectives, OARM will prevent soil erosion by replanting part of the tropical rainforest, erecting stone walls.

7 Constraints to Arresting and Reversing Land Degradation in Sri Lanka

There are serious land degradation problems in Sri Lanka. An expert group should be appointed by the Minister of Forestry and Environment to examine these problems and recommend short-term solutions. Detailed information on soils is limited. The available information is also scattered amongst several agencies. There is a need to collate all the available data on soils and identify data gaps that have to be filled so that a good soil database could be prepared for the country. The Ministry of Forestry and Environment should provide the necessary assistance to achieve this objective. The Ministry of Forestry and Environment should take steps to appoint an expert group to examine strategies currently adopted to mitigate the effects of drought in Sri Lanka and to formulate national policies in consultation with representatives of the victims to mitigate the effects of droughts. Reduced land productivity due to land degradation has substantial economic costs. The Ministry of Forestry and Environment through its economics affairs unit should initiate action to examine and quantify these costs. The Minister of Forestry and Environment should prepare and disseminate suitable programs to make school children aware of the socio-economic and environmental implications of land degradation. The Ministry of Forestry and Environment should take necessary steps to make community leaders, including politicians, aware of the importance of preserving and sustaining the productive capacity of both utilized and unutilized lands (Figs. 16.13 and 16.14).

Fig. 16.13 Stone walls were built by the local community to combat erosion

Fig. 16.14 Community consultation is an important part of the development of land use plans

7.1 Climate Change and Its Impacts on Agriculture, Forestry and Water

Since the most significant land degradation process occurring in Sri Lanka is soil erosion due to rainfall, studying the effects of climate change on soil erosion is vital. Higher rainfall intensities not only enhance splash erosion, but also generate higher surface runoff. The final result is enhanced soil erosion, leaching of plant nutrients along with off-site effects such as deposition/siltation and flash flooding. Moreover, extreme rainfall events can trigger landslides although those are also related to the spread of human settlements into unsuitable areas which are prone to landslides. In contrast, low rainfall situations can create higher atmospheric water demands resulting in higher evapo-transpiration. Higher evapo-transpiration can aggravate salt accumulation in lowlands resulting in abandonment of cropping. This situation will be more apparent in dry and coastal areas. On the other hand, increased temperature will alter soil chemical, physiochemical and biological environments, out of which the most apparent would be the increased rate of degeneration of soil organic matter, which results in enhanced soil erosion. Furthermore, the temperature rise will increase the situations with salt affected soils, resulting in loss of lands from agriculture. Water logging conditions and sea water intrusions which are associated with coastal zones are expected to be on the rise due to increase in sea water levels. Loss of land due to rise of sea level would also be significant for Sri Lanka. Curtailing land degradation in the face of possible scenarios of climate change is essential (Wickramasinghe and Munasinghe 2009).

7.2 Institutional and Governance Issues

Duplication of mandates and the fragmented nature of the responsibilities of different institutions were also identified as capacity constraints. These constraints could be eliminated by critically reviewing the mandates and responsibilities of the relevant institutions.

At the systemic level, the lack of co-operation between the central government and the provincial governments is one of the capacity constraints that prevent the successful implementation of the CCD in Sri Lanka. Formulation of a viable strategy or a program to strengthen the links between the central government and the provincial governments will be needed for better co-operation. At the same time there is a need to establish a nationally responsible authority to coordinate the institutions, implement the strategies, policies and programs to combat land degradation. There is no sound policy that addresses land degradation issues in the country. There is an urgent need therefore to formulate such a policy through relevant stakeholder participation (including NGOs and CBOs) and legally adopt it.

The policy should be developed within the framework of a sustainable development plan of the country. Preparation of the NAP by the MOE reflects the importance of soil conservation in combating land degradation in the country. There has to be a scientific input in to the decision-making process that needs to be strengthened. Generally speaking developing countries give low emphasis and a low priority to land degradation issues and Sri Lanka is no exception. Some strategies or programs should be developed in order to create awareness amongst stakeholders and educate them on the importance of combating land degradation. There is limited political interest and political will to combat land degradation in Sri Lanka. Changes in the political situation and changing political manifestos are also identified as constraints that prevent the implementation of UNCCD. The manifestos of successive governments have not addressed the direct and underlying causes of land degradation although some attention has been focused on the underlying causes such as in organic farming. What are needed therefore are concrete policies and strategies to combat land degradation in Sri Lanka. Hitherto, most of the development programs and projects of the government and private sectors have been designed and implemented at the expense of environment. Enacting new laws to safeguard the environment could help address this problem.

Programs to strengthen the links between the central government and the provincial governments will be needed for better co-operation. At the same time there is a need to establish a nationally responsible authority to coordinate among the institutions, implementing strategies, policies and programs to combat land degradation. Policies/legislation/strategies and programs on behalf of the government are generally formulated at institutional level by relevant ministries, government departments and statutory bodies. They are implemented after the approval by the Cabinet of Ministers of the government. However, during the formulation process all relevant stakeholders are not consulted and views of some stakeholders are not respected. As a result, some over lapping and duplication of activities may take place. These constraints must be overcome through proper consultation and participation of relevant stakeholders during the formulation process.

At the individual level, high-level officers should have the ability and skills to conceptualize and prepare policies/legislation/strategies and programs. However, many of the high level officers may not have the skills in the preparation and writing of projects proposals and programs. Their capacity constraints could be overcome by providing proper training, by improving necessary skills, by improving their awareness about the land degradation problem and by changing their attitudes.

Even though there are number of policies, laws, strategies and programs, these are not fully implemented. One of the main reasons for this situation is the improper mobilization and management of human and physical resources by the central government institutions and local government institutions. The lack of co-operation between the central and provincial governments in implementing policies and programs etc. is yet another factor that adversely affects and hampers implementation. Furthermore, there is no political interest or political will to combat land degradation in Sri Lanka. This also negatively impacts on the implementation of policies, plans and programs. Changes in subject areas, portfolios and ministries, relevant focal agencies, and decisions making high-ranking officers etc. also adversely affect on the planned programs and projects/policies.

Although implementation is the prime responsibility of institutions, there are institutional problems in implementing policies, laws, strategies and programs. The new *Land Use*, *Soil and Water Conservation Act* should be implemented immediately. The draft Land Use Policy should be revised to include the provisions to combat land degradation issues in Sri Lanka. Once the Cabinet approves the Land Use Policy, it should also be adopted immediately. Negligence on the part of some agencies who control over the limited natural resources have to be identified and actions taken to implement effectively the provisions in the existing policies, legislations and strategies. Inadequate human and physical resources and the inability to mobilize them is a major capacity constraint at the institutional level.

There are no immediate impacts/effects from soil conservation activities to the end users of lands such as rural farmers and the community in general at the individual level. As a result, there are problems in implementing the policies, strategies and legislation at the grass root level. These problems could be identified as the underlying causes or capacity constraints that prevent the implementation of the activities of CCD. Other underlying causes that prevent the implementation of CCD at the individual level are the attitudes and the lack of awareness on land degradation issues, the lack of knowledge and accessibility to new technologies and farming systems, low priority given to soil conservation, treating land as an unlimited resource, land ownership/tenure and the fragmentation of lands. These underlying causes can also be identified as capacity constraints at the individual level. Creating awareness and changing the attitudes of farmers could be the solution to overcome the constraints.

Grass root level, officers involved in the process also work ineffectively and hamper the overall implementation of activities related to combating land degradation and the promotion of soil conservation measures in the country. Skills development, increased salaries and training on career development etc. for the officers involved in the field of land degradation should be enhanced/improved in order to overcome this capacity constraint.

Lack of a proper information exchange system is a major drawback in incorporating national strategies in sustainable development plans and policies. This has been highlighted in various forums and national reports. It is necessary to have an effective coordination mechanism among the institutions (government, private and relevant stakeholders) for the exchange and analysis of information and identifying the problems and finding solutions. In this connection it would be very useful to establish a national level coordinating body. Presently, there is no such coordinating mechanism or coordinating body in Sri Lanka. This is one of the major capacity constraints that prevent or slow down the implementation of the CCD activities.

At the institutional level, it is necessary to have a coordination mechanism and a body to mobilize the information and knowledge available with different institutions. Besides, the lack of a proper inventory of experts in the field, the absence of a formal system of collecting information and the lack of proper consultative approach (team approach) inhibit the mobilization of information and the knowledge and thereby prevent the implementation of the requirements of CCD.

Attitudes of all stakeholders are very important in mobilizing and sharing the information. Officers especially those in the government sector are generally reluctant to share the information and knowledge with others. This is common not only amongst the scientific community but also at the administrative level where the data and statistics are handled. The reasons for this may be twofold; either the officer does not have the authority to disclose the information, or the officer does not wish to share the information with others (attitudes). At times, the relevant stakeholders are not consulted and their views are not respected in the process of mobilizing and sharing information. There is a lack of farmer's awareness of the magnitude and consequences of land degradation in Sri Lanka. The inability of farmers to perceive significant gains from activities pertaining to combating land degradation is also factors that prevent the implementing of activities to combat land degradation.

8 Conclusion

Sri Lanka is committed to the implementation of the NAP process. Preparation of the NAP by the MOE reflects the importance of soil conservation in combating land degradation in the country. The country has developed the structures to implement this but there is a need to build more capacity for implementation of the CCD. There is also need to build more capacity to improve on implementation, monitoring and evaluation of programs for combating desertification. A major obstacle in the way of combating land degradation is the absence of a National Land Use Policy. A draft Land Use Policy was prepared some time ago. The Minister of Forestry and Environment should take the lead role in overseeing the preparation of the final policy.

The National Action Plan (NAP) that is generated under the CCD is an effective policy instrument to promote sustainable management of land and land based resource management and related socio-economic and environmental issues. The success of the process involves the participation of all stakeholders in desertification combating efforts. The main challenges in its efforts to combat desertification include high human population growth in an economy whose development relies on utilization of natural resources, conservation of biodiversity, stabilizing sand dunes formed in arid zone areas, establishment of forest plantations on sensitive areas and involvement of local communities in conservation processes.

The most important pre-requisite for the implementation of a soil conservation program is the development of a sound land use policy for the country to provide the guidelines to the government, private sector and the community.

Acknowledgements A synthesis of this nature necessarily involves drawing upon the plethora of sources some published some in less accessible reports that have been prepared under the auspices of the government of Sri Lanka, by the UN system and by the donor community including NGOs. The authors are grateful to all those people whose materials formed the fabric of this chapter and the government of China for the opportunity to attend and participate in the Desert technology training course in Wuwei in 2006.

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Part V
Combating Desertification in the Middle East

Efforts to control desertification and arrest and reverse land degradation have a high priority in the Middle East. Two countries (Iran and Oman) are chosen as examples. Iran is a large country with high mountains, extensive deserts and plains that has problems: the mobile sand dunes, salinization and severe overgrazing. Vegetation plays such an important part in soil protection as well as a forage resource. Chapter 17 describes the key vegetation types and changes due to desertification. Chapter 18 focuses on soil and warer conservation efforts. Oman, a much smaller country, has problems in its coastal area as well as in the management of the inland areas.

Chapter 17
Indigenous Plant Species from the Drylands of Iran, Distribution and Potential for Habitat Maintenance and Repair

G. Ali Heshmati

Synopsis This chapter presents an overview of the main vegetation types within the drylands of Iran and discusses the implications for biodiversity conservation and the role that indigenous plants can play in rangeland rehabilitation. Examples are presented of successful re-vegetation efforts.

Key Points

- Environmental (topography, climate) features have an important role on plant diversity and richness of Iran. On the basis of environmental factors, four ecological zones were established on the basis of specific plant richness from lowest area to highest area (Hyrcanian, Khalij-O-Omani, Zagross and Iran-O-Touranian zones) respectively. Elevation is from –28 m which is close to Caspian Sea to 5,678 m which is located in the Alborz mountains. Two mountains (Alborz and Zagros) play a role as a wall that does not allow the moisture to go to the center of Iran (rain shadow effect). About 8,000 plant species of Iran, the most of them with different life forms (Herb, Grass, Shrub and tree), are distributed in Hyrcanian zone that is located in the northern part of Iran. In contrast, the lowest plant diversity is in the southern part of Iran (Khalij-O-Omanian zone), which is a flat area.
- The highest vast area (Iran-O-Touranian) is distributed in the center of Iran which is divided into two divisions with mountain part and plain area. The western part of Iran (Zagros zone) is affected by Mediterranean and Black sea moisture which has snow in the winter and low plant species with herb, grass, and tree life forms. Topography and climate factors have important affect on plant distribution and richness of Iran and they play an important role on ecological biodiversity of this country

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- Iran has 86 million ha of natural grazing land. Over the last 50 years, most of the semi-arid rangeland in Iran has been converted to cropland without an equivalent reduction in grazing animal numbers. This shift has led to heavy grazing pressure on rangeland vegetation. Iran is endowed with a rich diversity of families, genera, and species (8,000 species) of plants. As a significant source of the world's genetic resources and plant biodiversity, the consequence of increased grazing pressure on Iran plant diversity is of great interest and has been studied with a view to devising more sustainable grazing practices. The dryland is suffering from increased desertification. More and more of the once vegetated land is becoming barren and bare. This loss of vegetation not only leads to desertification, but also contributes to global climate change because of the decreased capacity of the environment to absorb carbon from the atmosphere.
- Exclusion can be considered as a management tool for restoring rangelands vegetation. Exclusion of livestock either on a long term basis, or seasonally, is a simple and inexpensive method of restoration and improvement of rangeland. Appropriate management practices and adopting suitable restoration procedures to enhance the level of rangeland renewal and restoration of rangelands, requires enough information and knowledge on rangeland ecosystems. Since vegetation coverage forms a substantial portion of natural ecosystems structure, therefore, its studying and examining is the first step toward gaining scientific knowledge, accurate understanding of phenomena and events taking place in the rangeland ecosystems. In addition, rangeland managers observing the status of plants inside exclusion and comparing it with outside the exclusion can assess the condition of rangeland inside and outside of the exclosure.
- Large-scale re-vegetation using both indigenous plants (mainly shrubs like *Haloxylon* spp.) and imported species (principally *Atriplex canescens*) has been conducted as part of participatory projects designed to relieve poverty, improve rangeland productivity and teach skills in nursery practice, plant propagation and re-vegetation technology.

Keywords Biodiversity • Ecological zone • Physiogeography • Climate • Rain shadow • Revegetation • Exclusion of grazing • Shrubs • *Atriplex* • *Haloxylon* • Sand dunes

1 Introduction

The Islamic Republic of Iran (I.R.IRAN) with area of about 1,648,000 km^2 is located in the southwest of Asia and lies approximately between 25°N and 40°N in latitude and between 44°E and 64°E in longitude. Iran with an area of more than 1.6 million km^2, Iran is the sixteenth largest country in the world. Placed in the Middle East and surrounded by the Armenia, Azerbaijan, Caspian Sea, Turkmenistan on the north, Afghanistan and Pakistan on the east, Oman sea and Persian Gulf on the south and Iraq and Turkey on the west. Population of Iran is about 70 million and the growth rate estimated as 1.7 % and it has 30 Provinces.

Fig. 17.1 Geographical location and topographic features of Iran. Elburz and Alborz are alternative spellings for the principal east-west mountain chain

Iran's important mountains are Alborz and Zagros ranges (Fig. 17.1). Alborz and Zagros Chains stretch in northwest-northeast and northwest-southeast direction. Damavand peak with a height of 5,600 m a.s.l. and Caspian coastal area with −28 m elevation are the most extreme values of land elevation in the country. The area within the mentioned mountain ranges are high plateau with its own secondary ranges and gradually slopes down to become desert which continues into southern part of Afghanistan and Pakistan border. Elevation ranges from 500 to 2,500 m. These important mountains play a crucial role in the non-uniform spatial and temporal distribution of precipitation in the whole country.

The country's climate is mainly arid or semi-arid, except the northern coastal areas and parts of western Iran. The climate is extremely continental with hot and dry summer and very cold winter particular in inland areas. Apart from the coastal areas, the temperature in Iran is extremely continental with relatively large annual range about 22–26 °C. The rainy period in most of the country is from November to May followed by dry period between May and October with rare precipitation. The average annual rainfall of the country is about 240 mm with maximum amounts in the Caspian Sea plains, Alborz and Zagros slopes with more than 1,800 and 480 mm, respectively.

Going inland at the central and eastern plains, precipitation decreases to less than 100 mm annually depending on the location. From the synoptic aspects, the climate of most part of Iran is dominated by subtropical high for most of the year. This phenomenon causes hot and dry climate in summer. The rainfall in the country is produced by Mediterranean synoptic systems, which move eastward along with westerly winds in the cold season. Synoptic systems and year-to-year variation in the number of passing cyclones cause high variability in annual rainfall. Frontal Mediterranean cyclones associated with the westerly air flows produce most of the precipitation in the whole country in late autumn and particularly in winter. In addition to the frontal Mediterranean cyclones, rainfall bearing systems called Sudanian cyclones which come from the southwest make an important contribution to increase annual rainfall amount of the west and southwest of the country (Raziei et al. 2005).

In northwest mountainous regions, convective and frontal thunderstorms are important atmospheric processes responsible for rainfall in spring and early summer. These rainfall bearing systems are active only in the west portion of the country and have no more energy and moisture to pass farther east. These systems sometimes may reach central and eastern dry regions of the country but have no potential to produce rainfall due to long trajectory and loss of moisture. This region is the most drought prone area in the country due to high inter- and intra-annual irregularity in rainfall and high coefficients of variation. This region that accounts for over half of the country area, is surrounded by Alborz mountain range from the north and Zagros range from the northwest to southwest. Zagros range acts as a wall to prevent Mediterranean moisture bearing systems to pass through to the east. Hence these two ranges prevent the arid and semi arid regions of the central and eastern part of Iran from access to moisture. This phenomenon gives rise to high irregularity in rainfall in the center of Iran. Lack of rainfall in May to October compounded with high temperature leads to high evapo-transpiration and water deficit in this region.

2 Geobotanical Features

Most parts of Iran are desert. Iran has a serious shortage of water and wood resources. Just the northern part of Iran, is green. Further south, i.e. the north beach of the Persian Gulf and Oman Sea, is desert because of the rain shadow effect of the Alborz mountain range. The humidity of Caspian Sea is blocked and this makes the North green (Fig. 17.2).

Since Iran is in the arid zone, some 65 % of its territory is arid or hyper arid, and approximately 90 % has an arid, semi-arid or hyper arid environment the specific features and location of Iran causes it to receive less than a third of the world average precipitation (Table 17.1).

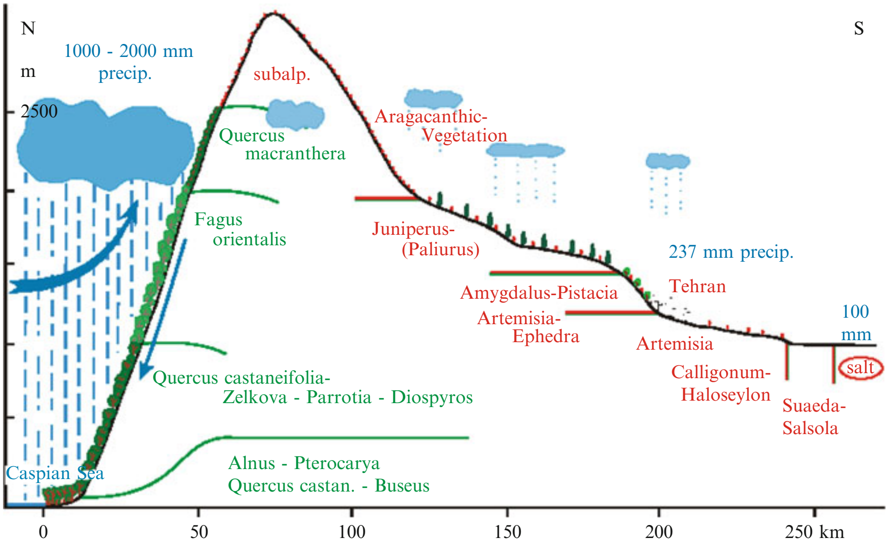

Fig. 17.2 Natural vegetation and elevation level on different aspects of Alborz mountain

Table 17.1 Most of the country is arid and hyper arid

Area	Hyper arid	Arid	Semi arid	Dry-sub humid	Total
World	7.5	12.1	17.7	9.9	47.2
Asia	6.5	14.7	16.3	8.3	45.8
Iran	35.5	29.2	20.1	4.9	89.7

Prolonged drought in this area and low available moisture in different parts of Iran have produced different ecological zones. Iranian habitats support about 8,000 species of flowering plants (belonging to 167 families and 1,200 genera), of which almost 1,700 are endemic (Eftekhari and Ramezani 2004).

The plant species growing on four Ecological Zones (Fig. 17.3) are subjected to different physiographical and climatic conditions. These four ecological zones are:

- **Hircanian**
- **Zagross**
- **Iran-O-Touranian**
  - **Plains**
  - **Mountain**
- **Khalij-O-Ommanian**

Each of these four ecological zones supports a suite of plant species which are adapted to the local conditions.

Fig. 17.3 Distribution of four ecological zones of Iran

2.1 Hircanian (Caspian) Zone

The region, extends throughout the south coast of Caspian Sea and northern part of the country which is bordered by the largest lake in the world. Mountains dominate the landscape of this ecoregion. Hircanian (Caspian) Zone could be divided into three subdivisions on the basis of geographical situations(.) These subdivisions are (1) Alborz Range forest steppe, (2) Caspian Hircanian Mixed Forest and (3) Caspian lowland desert.

Alborz range forest steppe: The highest peak in the Alborz Range is Mount Damavand, a dormant volcano 5,766 m tall. Below Mount Damavand's crater are two small glaciers, as well as fumaroles, hot springs, and mineral deposits. Only between 280 and 500 mm of precipitation falls annually on this high elevations of Alborz mountain. The dominant trees (*Juniperus sabina*, and *J. communis*) are resistant to summer drought and heat and can tolerate winter cold equally well. However, the trees grow so slowly that it is difficult to reestablish these forests once they are cut. Shrubs include pistachio, *Berberis integessima*, *Acer* spp., and *Amigdalus* spp., with *Onobrychis cornuta*, *Astragalus gossipinus*, *Agropyron* spp., *Bromus Tomentellus* forming the ground cover.

A network of large reservoirs supplies water to Iran's capital, Teheran, but harnessing the water has severely disrupted aquatic ecosystems. Overgrazing at higher elevations by sheep and the continued fragmentation of habitat, which is accelerated by road construction, are also of concern because so few natural areas remain.

Caspian hircanian mixed forest: Hircanian forests extend for 800 km in length and covers an area with 1,925,125 ha in the mid elevation of the middle altitudes of the Alborz mountain. The Caspian Hircanian Mixed Forests experience abundant rainfall and snowmelt that runs off the north slope of the Alborz mountain. It has high production capacity due to humid temperate climate and suitable soil.

The key trees of this area are: *Fagus orientalis*, *Carpinus betulus*, *Tilia rubra*, *Taxus baccata*, *Ulmus glabra*, *Quercus castanefolia*, *Parrotia persica*, *Alnus glutinosa*, *Punica granatum*, *Paliurus spira-ehristi*

These forests sweep down to the coastal plain south of the Caspian Sea, where they eventually yield to coastal lagoons, swamps, and salt marshes. Extensive logging and clearing of forests for agriculture have nearly eliminated the forests in this ecoregion. The invasion of non-native plant species has also posed a serious threat to native plant communities.

Caspian lowland desert: This ecoregion encompasses on the southern and eastern shores of the Caspian Sea at elevations between −28 and 100 m above sea level. To the south of the Caspian Lowland in Turkmenistan and Iran lies the delta of the Atrek River – the only river to enter the Caspian Sea from the east (Babaev 1994); Most of its flow is used for irrigation so only flood waters actually reach the sea. Average annual temperature is 17.1 °C. Annual precipitation is 187 mm (Heshmati 1998). A long frostless period (271 days) encourages cultivation of crops such as olive, fig, pomegranate, and cotton.

This ecoregion are covered by shrubs and grasses which are used by livestock. The vegetation of the coastal Caspian desert within Iran is impoverished, it consists of highly specialized halophytes (salt-resistant plants) represented by shrubs and semishrubs such as various sagebrushes (*Artemisia*), tetyr (*Salsola gemmascens*), kevreik (*S. orientalis*),boyalych (*S. arbuscula*), biyurgun (*Anabasis salsa*, *A. ramosissimum*), sarsazan (*Halocnemum strobilaceum*), *Halostachys*, *Ceratocarpus*, *Nitraria*, *Kalidium*. Herbaceous vegetation is represented by species of *Aristida*, *Peganum*, *Agropyron*, *Anisantha*, *Eremopyrum*. One of the most typical halophyte plant formations is dominated by tetyr (*Salsola gemmascens*), a 30–50 cm shrub, associated with low species diversity and sparse coverage. Solonchaks are sometimes occupied exclusively by sarsazan (*Halocnemum strobilaceum*). This ecoregion encompasses the Caspian depression of Kazakhstan, the Karabogaz Kol in Turkmenistan and includes the Volga Delta and surrounding semi-desert. Within Central Asia, it is defined by deserts and halophytic regions of the syrt regions according to Pereladova et al. (1997) map of Central Asian ecosystems. Adjacent Iranian littoral salt land vegetation from Zohary's (1973) geobotanical map of the Middle East is also included since it represents a similar halophytic environment. The European portions of the ecoregion consist of northern lowland dwarf semi-shrub deserts and small areas of floodplain vegetation and coastal and inland

Table 17.2 Key plant species of Hircanian zone (Heshmati 1999)

Land use	Habitat	Altitude (m)	Key plant species
Forest	Shrub	>1,800	*Juniperus sabina*, *J. communis*, *Acer* spp., *Berberis integessima*, *Amigdalus*, spp.
	Tree	800–1,800	*Fagus orientalis*, *Carpinus betulus*, *Tilia rubra*, *Taxus baccata*, *Ulmus glabra*
	Tree + Shrub	<800	*Quercus castanefolia*, *Parrotia persica*, *Alnus glutinosa*, *Punica granatum*, *Paliurus spina-christi*
Rangeland	High Altitude	>1,800	*Onobrychis cornuta*, *Astragalus gossipinus*, *Agropyron* spp., *Br. Tomentellus*
	Middle	800–1,800	*Dactylis glomerata*, *Poa bulbosa*, *Trifolium pratense*, *Onobrychis* spp.
	Lowlands: Shrubs	<800	*Tamarix ramosisima Halostachys caspica*
	Lowlands: Shrubs + Herbs	<800	*Halocnemum strobilaceum*, *Salicornia herbaceae*
	Lowlands: Grass + Shrubs	<800	*Artemisia siberi*, *Poa bulbosa*

halophytic vegetation north of the Caspian Sea (Bohn et al. 2000). Heshmati (1999) has published the key plant species of Hircanian (Caspian) Zone which is located in northern part of Iran on the basis of land use, habitat and altitude (Table 17.2).

2.2 Zagross Zone

The Zagross ecological zone extends throughout the Zagros mountain in the west and south – west of Iran, west Azerbaijan, Kordistan, Kermanshah, Lorestan, Fars, Charmahal & Bakhtiyari, Yasouj and north of Khozistan. This region with an area of about 4,749,000 ha has semi – arid climate and temperate winter. This mountain range parallels the Persian Gulf and consists of numerous parallel ridges, with the highest peaks exceeding 4,000 m and maintaining permanent snow cover. Many large rivers, including the Karun, Dez, and Kharkeh, originate here, draining into the Persian Gulf or the Caspian Sea. Scenic waterfalls, pools, and lakes add beauty to the mountainous landscape.

The forest and steppe forest areas of the Zagros Mountain range have a semi-arid temperate climate, with annual precipitation ranging from 400 m to 800 mm, falling mostly in winter and spring. Winters are severe, with winter minima often below −25 °C, and extreme summer aridity also prevails (Anderson 1999; Frey and Probst 1986).

As characterized by Zohary (1973), the Kurdo-Zagrosian steppe-forest consists mainly of deciduous, broad-leaved trees or shrubs with a dense ground cover of steppe vegetation. The dominant species are oak (*Quercus* spp.), pistachio (*Pistacia* spp.) and a few others. In the northern reaches of the mountain range, lower altitudes (400–500 m) host communities dominated by *Astragalus* spp., *Salvia* spp., or others while higher up (700–800 m) forests or forest remnants of *Quercus brantii* and/or *Q. boissieri* occur up to an altitude of about 1,700 m. Above the timber line (1,900–2,000 m) a relatively wide zone of sub-alpine vegetation grows (Zohary 1973).

Further south along the range, the forest becomes more impoverished and a richer steppe flora develops among the trees. Forest remnants consist primarily of *Quercus persica* and, up to an elevation of 2,400 m, xerophilous forest of *Quercus* spp., hawthorn (*Crataegus*), almond (*Prunus amygdalus*), nettle tree (*Celtis*) and pear (*Pyrus* spp.) predominates. Below 1,400 m, the vegetation is steppic, with shrubs predominating.

2.3 Iran-O-Touranian Zone

The region covers an area of about 3,452,775 ha with dry and mainly cold climate in winter. They are situated in Khorasan, Azarbaijan, Markazi and western Provinces. Based on topographical conditions and diversity of species, the region is divided into plain and mountainous sub – regions.

2.3.1 Iran-O-Touranian, Plain Area

This ecoregion is dominated by the central Iranian plateau, an immense area covering 1,648,000 km^2 in the center of Iran and encompassing a great variety of climates, soils and topography. It is almost completely surrounded on all sides by mountain ranges. According to Zohary (1973), the area can be divided into two major units: the Dasht-e-Kavir in the north, a vast saline desert, and the Dasht-e-Lut in the south, largely a sand and gravel desert and one of the hottest deserts in the world. The plateau is also partly covered with sand dunes. Adjacent regions, such as the Kavir-e-Namak ('salt desert') and a series of marshes and lakes east of Qom, are also included in this ecoregion (Zohary 1973). In the northwestern corner of the central plateau, where the Kavir National Park is situated, habitat types range from desert and semi-desert to dry steppe. In the northeastern reaches of the plateau, in the area of the Touran Biosphere Reserve, the variety of landforms includes extensive plains, a saline river system, alluvial fans, limestone outcrops, salt desert, and 200,000 ha of the northern most sand dunes in Iran (UNEP-WCMC 1989; Boulos et al. 1994). The peaks and ranges of the Kuhrud Kohbanan Mountains forest steppe ecoregion encroach upon the higher altitudes of this region, extending long fingers in a northwest-southeast direction along the western and central part of the plateau and also rising along its eastern margins.

The central plateau and the mountain slopes facing it have a temperate, continental desert climate with extreme temperatures (Zohary 1973). While the mean annual temperature ranges from 15 to 18 °C, the extreme maximum temperature can reach 42 °C. and the extreme minimum temperature can fall to −20 °C. In most of the region, annual rainfall does not exceed 200 mm and in much of it, rainfall is less than 100 mm (Zohary 1973). In the northwest corner of the region, precipitation is highly variable from year to year, ranging from less than 50 mm to over 300 mm and falling mostly as rain from November to May (UNEP-WCMC 1989). The driest parts of Iran are found in the central and eastern parts of the plateau, with the Dasht-e-Hut receiving only up to 50 mm per year. The low amount of rainfall is aggravated by high evaporation rates.

The rivers descending into the central plateau from the surrounding mountain ranges carry high levels of soluble salts, and the ground in the plateau tends to be highly saline (Zohary 1973). On the margins of the plateau, and in a few patches in the interior where the topography is such that the soil is less saline, areas of piedmont fans and alluvial soils exist and can be farmed. Zohary (1973) differentiates the central plateau into a series of habitats, including poorly drained flats inhabited by halophytic communities and better drained flats inhabited by a variety of sagebrush (*Artemisia*) steppes. The flats are interspersed with sand dunes and gravel deserts. True sand deserts, consisting of vast dune fields, exist in Iran only in the central plateau and cover a surface area of about 183,000 km^2; they are found at altitudes of about 500–1,200 m.

According to Zohary (1973), the central Iranian sector hosts the most typical vegetation of Iran's steppe and desert regions. Dwarf scrub vegetation is common in large areas of the interior of Iran and is very diverse and rich in species; in non-saline areas, a variant with many thorn-cushions (Zohary 1973) is formed. Under extremely arid conditions, a very open variant of the dwarf shrublands appears, also characteristic of large areas of the Iranian interior; the dominant species are sagebrush (*Artemisia siberi*, *Astragalus gossypius*), and others (Frey and Probst 1986). In areas receiving over 100 mm of rain, other genera such as *Pteropyrum*, *Zygophyllum* and *Amygdalus* can also be found.

With regard to vegetation of the sand deserts in the interior regions of Iran, among the more characteristic genera are *Ephedra*, *Calligonum*, *Heliotropum*, and others (Frey and Probst 1986). Endemic shrubs and perennials include *Astragalus* (*Ammodendron*) *kavirensis, Heliotropum rudbaricum*, and others. Many species here are highly specialized as psammophytes; these sand-adapted species are estimated to make up one third to one half of the total number of species in the sand deserts of Iran and Afghanistan (Freitag 1986). Iranian deserts also have a striking number of *Tamarix* species; they have been reported to occur on the margins of the more sandy and gravelly parts of the Dasht-e-Lut (Breckle 1983).

Halophytic communities of varying composition are found on the margins of the undrained salt pans of the central Iranian region, such as the Dasht-e-Kevir. In such areas, clays and sand soils have a high surface salt content due to insufficient water and high summer evaporation. Characteristic genera and species include *Aellenia* spp., *Halocnemum strobilaceum*, *Haloxylon* spp., *Salsola* spp., and others (Frey and Probst 1986). The inner parts of the salt pans have almost no vegetation. Zohary (1973) points out that saline soils can harbor an impressive number of plant communities, and he characterizes Iran as "outstanding in its rich

Fig. 17.4 The Caspian ecoregion has a great diversity of halophytes

halophytic flora and vegetation due to the abundance of saline habitats". He notes that Touranian stock in the central plateau region, particularly that of the dunes and saline areas, has supplied numerous taxa and their derivatives, especially halophytes and psammophytes, to the Old World northern subtropical deserts (Fig. 17.4).

2.3.2 Iran-O-Touranian, Mountain Zone

In mountainous sub-region the *Juniperus polycar* species are developed . The sub-region has dry and cold climate, temperate summer and the annual precipitation is about 400 mm. The plain sub- region is dominated by desert climate and hot summer. A variety of fruit trees, medicinal, industrial, and edible plants found in the mountain ecoregions of the Iran-O-Touranian Zone. The plant species of these regions are: *Amygdallus scoparia*, *Onobrychis cornuta*, *Acantholimon* spp., *Astragalus* spp., *Artemisia aucheri*, *Allium* spp., *Bromus tomentellus*.

2.4 Khalidj-O-Ommanian Zone

The region with an area of 2,130,000 ha extends throughout southern parts of the country in Khosiztan, Boushehr, Hormozgan and Sistan- Baluchistan provinces. They are dominated by sub-equatorial climate. The main species in the region are: *Acacia- Prosopis- Ziziphus- Avicennia- Rhizophora- Populus euphratica- Prosopis stephaniana*

The indigenous plant species of the above ecological zones are classified on the basis of average rainfall, altitude, utility and longevity in Table 17.3.

Table 17.3 Distribution of the key plant species of dryland habitats on the basis of ecological needs in Iran

Key species	Life form	Habitat	Altitude	Precipitation	Utility	Longevity
Juniperus communis	Shrub	Hircanian	>1,800	>450	Protection	Perennial
Fagus orientalis, *Taxus baccata*	Tree		1,800–800	600–800	Construction	Perennial
Quercus castanefolia, *Parrotia persica*	Tree + Shrub		<800	500	Construction + fuel	Perennial
Astragalus gossipinus, *Festuca ovina*	Shrubs + Grass		>1,800	>450	Grazing	Perennial
Dactylis glomerata			1,800–800–	300–450	Grazing	Perennial
Halocnemum strobilaceum, *Artemisia siberi*, *Poa bulbosa*	Shrubs + Grass		800<	300	Grazing	Perennial
Amygdalus scoparia, *Quercus libani*, *Q. Branti*	Tree	Zagross	8,000<	750	Construction	Perennial
Fraxinus rotundifolia, *Pyrus syriaca*	Shrub		2,000–1,200	750	Fuel + fruit	Perennial
Juniperus communis	Tree		>2,000	750	Protection	Perennial
Artemisia siberi Zygophyllum atriplicoides, *Haloxylon ammodendron*	Shrub	Iran-O-Touranian Plain	1,500–800	250	Grazing + protection	Perennial
Artemisia aucheri, *Bromus tomentellus*	Shrub + Grass		>1,500	400–200	Protection + grazing	Perennial
Acacia ehrenbergiana, *Tamarix Stricta Cenchrus ciliaris Avicennia germinans*	Tree	Khalidj-O-Omanian	1,000–0	400–70	Fuel, Wood + Industry	Perennial

3 Re-vegetation Based on Locally Adapted Species

Large-scale re-vegetation has been a feature of Iran's efforts to rehabilitate degraded rangelands (See Chap. 18).

3.1 Desertification and Its Control by Plant-Based Methods

Wind erosion and its destructive effects on natural resources and the environment has been a serious problem in Iran from olden times. Basically, wind erosion control involves land salvage and re-vegetation in areas that are subjected to it because of denudation. Although there had been efforts to control it, it was not until 1965 that an organized attempt for checking the phenomenon was launched by establishment of a station in an area of 100 ha south of Sabzevar, Khorasan province (See Chap. 18).

The objectives were protection of the environment; stabilization of shifting sands and dunes; preservation of farming lands, conservation of water resources including the Ghanat system, and water supply installations; protection of roads and water distribution networks; and reclamation of settlements and prevention of the inhabitants' emigration. The results of more than 25 years of sand dune fixation activities in the country are plantation of 1 Mha with seedlings and 2 Mha of seeding which has protected or rehabilitated more than 4 Mha.

3.1.1 What Techniques Work?

Doubtless the most rational and efficient way to stabilize the shifting sands, rehabilitation of plant cover and reclamation of ecological conditions. But since the soil is not stable, sometimes it is necessary first to stabilize it temporarily against movement with windbreaks or palisades (see Chap. 3) (Fig. 17.5).

Barriers comprised of shrubs, woven canes, and tree branches are placed over dunes in rows or cross-lined patterns help to protect the surface (Fig. 17.6).

Mulching the soil surface with petro-chemical derivatives is another efficient way of temporary stabilization of dunes and creating opportunity for seeds and seedlings to grow and strike root. Mulch is a substance obtained from petroleum during refining. Mulches, after extraction of aromatics and adding chemical additives as per formulation (which varies according to areas), is carried in tankers to the area. Mulches are heated there and sprayed over the soil by special devices (Fig. 17.7).

But for permanent stabilization of dunes, plant cover must be fully restored. This may be carried out through seeding, plantation of seedlings, and cuttings. The required seeds may be partly obtained from other planted areas and partly from natural forests of deserts. Locally adapted ecotypes provide the best seed source. The required seedlings are grown in nurseries either in beds or in plastic

Fig. 17.5 Tree and shrub seedlings are produced in irrigated nurseries that are protected by windbreaks and have water available for supplementary irrigation

Fig. 17.6 Prevention of the wind erosion can be achieved by covering the surface with obstacles that reduce wind velocity at the surface

pots. The most frequently used seedlings in stabilization of dunes are as follows: *Haloxylon* spp. *Tamarix* spp., *Zygophyllum eurypterum*, *Stipagrostis pennuata*, *Calligonum* spp., *Calotropis procera*, *Atriplex* spp., *Acacia* spp., *Prosopis spicigera*, *Nitraria schoberi and Panicum* spp. Dunes can be stabilized by a combination of biological methods involving planting shrubs and grasses inside small areas protected by pallisades (Figs. 17.8 and 17.9).

Fig. 17.7 Bulldozer towing oil/seed spraying equipment into position

Fig. 17.8 Dunes can be stabilized by a combination of biological methods involving planting shrubs and grasses inside small areas protected by pallisades

Fig. 17.9 Reclamation of desert lands with resistant species such as *Atriplex* spp. and *Haloxylon* spp.

To secure a satisfactory result, in arid areas it is necessary to irrigate the planted seedlings several times in the first two years. Water can be supplied through temporary pipelines or transported by tankers. Planted areas become completely stabilized and biologically productive after two or three years.

As a result of the implementation of dune stabilization and desert elimination programs, a good opportunity was provided for revegetation and restoration of the

Fig. 17.10 Harsh desert environments like this pose a real challenge to those who wish to re-vegetate

ecological conditions in the region, where the continuity of biological reproduction is assured by the restoration of nature's life cycle (Fig. 17.10).

Reclamation of natural resources and plant cover in desert lands is a difficult and challenging task, but it will bear fruitful results if it is carried out with rational and proper planning. Thus stabilization of dunes helps to protect residential areas, roads and valuable economic resources and so deserts, once bare and barren, become wood and fodder producing centers or become a source of fuel wood if planted to trees. Fuel wood is major problem (see Box 17.1).

Today, in Iran, as a result of implementation of dune stabilization projects, not only plant cover of vast expanses of deserts has been rehabilitated, but also parts of these lands have been converted to agricultural or industrial areas with vast farming lands and several industrial and economic centers.

More than a quarter of a century of widespread activities in the field of drifting – sand stabilization, and desert elimination, and the experience gained in their practical application, have placed Iran in the rank of the world's leading and authoritative countries, in regard of the practical application of sand stabilization and desert elimination programs.

Since the menace of the encroaching deserts and drifting sands constitutes the common problem of several countries in the region, as well as of certain areas of the Asian and the African continents, Iran's experience and the progress achieved by Iran in this field, may well constitute path-breakers for the interested countries (Fig. 17.11).

Fig. 17.11 Millions of plants are produced each year. Nurseries like this one are the backbone of this effort to reproduce locally adapted plants for transplanting (Photo Behrouz Malekpour)

Box 17.1: Carbon Sequestration in the Desertified Dryland

The Carbon Sequestration in the Desertified Dryland of Hosseinabad Project (CSP) was brought to life in 2003 through the joint efforts of the United Nations Development Program (UNDP), Global Environment Fund (GEF) and the Government of the Islamic Republic of Iran (IRI). The CSP is a unique project. It takes a holistic approach to achieving its goal, sequestering carbon by protecting the environmental integrity of the rangelands of Hosseinabad and the livelihoods of its inhabitants.

The dryland where the CSP focuses its efforts is suffering from increased desertification. More and more of the once vegetated land is becoming barren and bare. This loss of vegetation not only leads to desertification, but also contributes to global climate change because of the decreased capacity of the environment to absorb carbon in the atmosphere. When the architects of the CSP realized the problem, they aimed to address it through an innovative approach: social mobilization. Instead of taking the traditional top-down approach and imposing environmental mechanisms on the local people, they worked to "harness the dormant potential and the willingness of people to help themselves". In this way, the project kicked off in the belief that the fight against desertification is fundamentally a fight against poverty.

The CSP quickly set out to identify key causes of not only desertification but also poverty in order to achieve the Project's objective. One simple

(continued)

Box 17.1 (continued)

solution was the introduction of gas tanoor. Tanoor are traditional ovens used to prepare bread, a staple food in Iran. They are fuelled by wood; however, in the rangelands, the daily use of wood to fuel the tanoor was leading to the destruction of precious vegetation. This was becoming a major cause of the desertification of the drylands. The Sequestration Project, therefore, worked to introduce smaller gas fuelled tanoors that could be used by each family to prepare bread. This also had the bonus of granting the villagers, particularly women and children, more time to use on productive activities instead of having to roam the dryland in search of firewood. As a result of this initiative, over the last 6 years, the CSP has been able to reduce the consumption of firewood by local communities by 80.6 %.

In order to directly address the problem of desertification, the CSP has introduced another ingenious solution. They have created a large-scale vegetation nursery in the area. What makes it unique is that the nurseries are staffed and managed by local people; the project staff only provide minimal oversight. Once the plants are mature, the locals are paid to plant the shrubs in the affected dryland. So far, 13,572 ha of dryland have been successfully rehabilitated and a locally adjusted model for carbon sequestration has been developed.

"It is the local people who decide which plants we produce," says National Project Manager (NPM) for the CSP, Mr. Ali Reza Yari. "Since they are involved in every stage of the rehabilitation process, they understand the importance of the plants and do more to ensure their survival."

"We have now made moves to have mini-nurseries created in each village," adds Mr. Yari. "This way the process will be totally localised, and by next year, we hope that there will be no need for a large nursery site."

The first phase of the project had the humble budget of US$1.8 million, which was jointly contributed to by the Government, the UNDP and GEF. Over the 6 years of its operation, the CSP has shown that with some assistance, local communities are able successfully and cost-effectively restore and manage degraded environments while improving their own livelihoods. It also demonstrated that there is a link between environmental degradation and poverty, and that both can be addressed through the participation of local communities and stakeholders.

Given the success of the CSP, the Government and the UNDP have now agreed to jointly contribute US$2.1million for a second phase of the CSP so the project can be extended for another 5 years. The second phase of the project seeks to build on the successes of the past 6 years by strengthening the processes developed and expanding the CSP project area. It is also hoped that local communities will be able to assume responsibility and ownership for the restoration, conservation and sustainable use of the dryland.

(continued)

Box 17.1 (continued)

On many accounts the CSP is a success. At a local level the rehabilitation of the dryland and provision of new financial tools has helped fight the poverty in the local villages and slowly improve their quality of life. On a national perspective, it has helped provide a model for effectively preventing the desertification of rangelands of Iran. And from a global standpoint, the CSP has shown that local communities can help in the international efforts to combat climate change by rehabilitating dryland ecosystems that potentially play a significant role in absorbing atmospheric carbon.

4 Conclusions

Most of Iran is located in the Iran-o-Touranian zone. Iranian habitats support about 8,000 species of flowering plants (belonging to 167 families and 1,200 genera), of which almost 1,700 are endemic. The driest portions of Iran-O-Touranian, Plain zone are uninhabited, but in areas where enough rain falls to support habitation, humans have degraded the landscape. Agriculture, pastoralism, and woodcutting have caused the loss of natural vegetation. One of the serious threats to most of the Iranian ecosystems is drought, because much of Iran lies in the arid or semi-arid regions. The other threats for plants are: overgrazing, fuelwood extraction, conversion of forest and other wildlands for agriculture, road construction, overexploitation, and unscientific extraction of plant resources for medicine, food, and other uses. Among the overexploited species, some are medicinal plants, which were very abundant until a few decades ago, but are now endangered in their natural habitats.

A good knowledge of the ecology and eco-physiology of the indigenous plants is a basis for efforts to restore and rehabilitate degraded areas as well as a foundation for efforts to protect the biodiversity.

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Chapter 18
Soil and Water Conservation for Desertification Control in Iran

Ali Najafi Nejad

Synopsis An overview of both past and on-going efforts to arrest and reverse land degradation in Iran. Iran has areas vulnerable to desertification due to extensive areas of drylands and increasing population pressure on land and water resources. Overgrazing of rangelands is a particular problem. Initially desertification was combated mainly at the local level and involved dune stabilization measures, especially the use of oil mulch, re-vegetation and windbreaks. Several projects are summarized that illustrate the variety of the problems faced in this country that has a large arid zone.

Key Points

- There is an increasing need for research into desertification development and its causes as this can provide an important basis for desertification control strategies and rational planning of land use in arid and semi-arid areas. Desertification is a very complex process. In addition to natural conditions such as climate, vegetation, soil and so on, it involves many human economic activities, for example, agriculture and animal husbandry. Therefore, to combat desertification, one needs not only to improve natural conditions and raise land productivity, but also to ameliorate the use and management of natural resources in desertified areas.
- In 2004 a national plan to combat desertification was ratified and this placed an emphasis on community participation. Continuing challenges include managing existing desertified areas as well as taking into account potential future problems associated with rapidly depleting groundwater supplies and a predicted reduction in the plant growth period accompanying climate change.

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- There is no accurate estimate of soil erosion in different parts of Iran. But 20 years records from 120 gauging stations were examined to evaluate soil erosion and sediment yield in some watersheds in Iran. From 37 sub-basins in Iran, data from 24 of them were used for this study which covered more than 37 million hectares. The results show that watersheds under study have an average annual sediment yield of 750 t/km^2 and an erosion yield of 2,500 t/km^2.

Keywords Desertification • Iran • Water conservation • Sand dune fixation • Gully erosion • Landslides • Water spreading • Flood waters re-vegetation • Sediment yield

1 Introduction

Desertification is acknowledged to be a complex phenomenon requiring the expertise of researchers in such disciplines as climatology, soil science, meteorology, hydrology, range science, agronomy, veterinary medicine, as well as geography, political science, economics and anthropology. It has been defined in many different ways by researchers in these and other disciplines, as well as from many national and bureaucratic (institutional) perspectives, each emphasizing different aspects of the phenomenon. A review of the desertification literature shows a great diversity (and confusion) among definitions. This mix of definitions leads to miscommunication among researchers, among policy-makers, and most important, *between* researchers and policy-makers (see Chap. 1).

Some researchers consider desertification to be *a process* of change, while others view it as the *end result* of a process of change. This distinction underlies one of the main disagreements about what constitutes desertification. Desertification-as-process has generally been viewed as a series of incremental (sometimes step-wise) changes in biological productivity in arid, semi-arid, and sub humid ecosystems. It can encompass such changes as a decline in yield of the same crop or, more drastically, the replacement of one vegetative species by another maybe equally productive or equally useful, or even a decrease in the density of the existing vegetative cover. Desertification-as-event is the creation of desert-like conditions as the end result of a process of change. To many, it is difficult to accept incremental changes as a manifestation of desertification.

2 Desertification and Soil and Water Conservation in Iran

Iran which has more than 75 million population is located between the latitudes 25° to 30° N and longitudes 44° to 64° E, in the temperate zone and could be considered arid or semi-arid.

Only a small part of the country is humid, the annual precipitation throughout the country is about 250 mm. Eight percent of the country receives between 500 and 1,000 mm of precipitation annually. The maximum temperature during summer ranges from 34°C in the north to 50°C in the south. Most parts of the north and center of Iran receive snow during winter and temperature drops below freezing point. More than 90 % of the land area in Iran is classified as arid or semi-arid. Of the 164.8 million hectares (Mha) of whole area of the country, the mean annual precipitation of the 87 Mha of the mountainous regions and 77.8 Mha of the plains areas are 365 mm and 115 mm, respectively. Approximately one-half of Iran's water supplies come from surface waters, with most of the remainder coming from groundwater aquifers which are significantly over- drawn. Therefore, drought is an ever present threat to most of Iran.

2.1 Distribution of Deserts in Iran

Even though there is a variation in reports on the exact area of deserts in Iran, because of different definitions; some real estimations showed that, at the present the area of desert regions and sandy lands is estimated to be 34 Mha (5 Mha active and 12 Mha inactive sands and remaining areas is salt accumulation lands, saline and alkaline soils, gravelly lands, etc.) The eastern part of the plateau is covered by two salt deserts, the Dasht-e Kavir (Great Salt Desert) and the Dasht-e Lut (Fig. 18.1). Except for some scattered oases, these deserts are uninhabited. The area of the degraded and desertified rangelands is atleast 16 Mha but according to some assessments it could be as high as 50 Mha. To more accurately determine the area and status of the degraded rangelands will require an integrated survey to delineate and map Iranian rangelands and deserts, to get actual numbers and provide a baseline against which future changes can be assessed.

2.2 Land Degradation, Nature and Extent

Although agricultural activities and land use in Iran have a long history (from about 7,000 years B.P.) and despite of huge deterioration caused by soil erosion and flood there are some documents that show that increasing soil erosion is an outcome of land use practices in the recent century. The first comprehensive report of soil erosion, water and soil conservation was provided in English by FAO experts in 1958.

There is no accurate estimate of soil erosion in different parts of Iran. But 20 years records from 120 gauging stations were examined to evaluate soil erosion and sediment yield in some watersheds in Iran (Jalalian et al. 1997). From 37 sub-basins in Iran, data from 24 of them were used for this study which covered more than 37 million hectares. The MPSIAC method, which uses nine factors including

Fig. 18.1 Iran has a large arid zone. It borders on the Caspian Sea, the Persian Gulf and several Central Asian Countries to the east

surface geology, soils, climate, runoff, topography, ground cover, land use, upland erosion and channel erosion was employed to estimate erosion and sediment yields for watersheds without gauging stations. The results show that watersheds under study have an average annual sediment yield of 750 t/km^2 and an erosion yield of 2,500 t/km^2. The Karkheh, Sefid-rood, maroon, Hirmand and Zohreh watersheds had the highest annual sediment yields with 1,409, 967, 779, 722, and 704 t/km^2 respectively. It is estimated that the average annual erosion rate in watersheds of Iran is 20–30 times of the acceptable level. Intense erosion and sedimentation has been primarily caused by: (i) over grazing (estimated 76 million sheep currently being grazed on a land area with sustainable carrying capacity of only 26 million), (ii) dry farming on steep slopes and deforestation (Fig. 18.2).

Available information indicates that 59 % from 17 watersheds of major dams in Iran (about 8.8 Mha) are badly degraded. Further detailed studies are recommended for soil erosion estimation in different regions of Iran.

Fig. 18.2 Overgrazing leads to loss of vegetation and accelerated run off and soil loss (Photo by author)

Soil erosion, including wind or water erosions, is one of the most important elements of land degradation in Iran. Besides over-exploitation of land resources as a result of population growth and lack of proper solutions for land management are also accounted among other factors contributing to land degradation in Iran. Of the total land area of the Country, approximately 75 million hectares are exposed to water erosion, 20 million hectares to wind erosion and the remaining five million hectares to other types of chemical and physical degradations. As a result, about two million hectares are in danger of infertility, two million hectares are exposed to salinization and one million hectares are threatened by other types of degradation (Figs. 18.3 and 18.4).

Deforestation and desertification adversely affect agricultural productivity, the health of humans as well as of livestock, and economic activities such as eco-tourism. Land degradation and desertification in Iran have accelerated during recent decades due to the following factors:

- Population has doubled during the period 1979–2009.
- More agricultural and pastoral products have forced people to use land extensively or convert forest and rangelands to cultivated land.
- Over use of wood and plants as fuel for household cooking and heating tends to denude the soil and intensify desertification.
- Irregular and uncoordinated exploitation of water resources.

Fig. 18.3 Severe gully erosion in loess area

Fig. 18.4 Gully development is a kind of land degradation in Atrak river basin

Denuded soil is exposed to wind erosion and shifting sand dunes destroy orchards, gardens, farming lands and threaten industrial and economical centers and leads to total collapse of economy, devastation of the environment, abandonment of settlements and migration of people to cities or other residential centers. Wind erosion and its effects on natural resources and the environment has been a serious problem in the last 25 years. Iranian researchers carried out experiments and projects for decades on dune stabilization and rehabilitation of desertified lands.

The policies and programs to rehabilitate and develop renewable natural resources, with consideration for desertification control are as follows (Table 18.1):

- Public awareness about the importance of renewable natural resources (using the mess media).
- Socio-economic development in rural areas (to prevent the migration of farmers to major cities such as Teheran, Shiraz, Esfahan, Tabriz).
- Conservation of water resources including Ghanats system and water supply installations.
- Protection of roads and communications networks.
- Protection of the environment and restoration of ecological stability.
- Reclamation and Rehabilitation of degraded land.
- Sand dune stabilization to minimize negative effects on farmland.

3 Government Response to the Problem of Land Degradation

Typically there are two broad categories of response. The first of these is the legislative and regulatory framework. Particularly in the light of the synergism between the several international conventions (Biodiversity, Desertification, Climate Change) governments realize the need to create an enabling environment that permits compliance with the various UN conventions on environment.

3.1 Legislation and Regulation Relating to Land Degradation

The government of Iran has enacted several important pieces of legislation. Iran is signatory to the major international treaties (Climate change, Biodiversity, Desertification, CITES, and the Kyoto and Montreal protocols). Specific legislation has been enacted over the past 50 years and includes laws on *Pastures and Forestry, 1974*, and the revised *Forest Law, 2005*; and the *Plant Protection Law, 2005*.

Table 18.1 A review of available desertification control technologies in Iran

No.	Technique/methods	Sites where applicable	Limitations/benefits	Relative cost effectiveness	Overall rating
	Biological methods				
1	Shelterbelt networks to protect farmland	Within farmland Along banks of canal	Only a few tree species suitable Long-horned beetle damaged High consumption of water Good protection results Making micro-climate for crops Supplying timber	Relatively expensive Simple management Resulting in yield Reduction in the marginal field	4 Effectiveness 4 Durability 4 Maintenance
2	Sand fixation forest for fixing mobile send dunes	2/3 of leeward side of mobile dunes from bottom	Hard condition for shrubs to survive Labor demanding Long life (20–40 years) Fixing sand dunes	Cheap Relatively easy to maintenance	4 Effectiveness 4 Durability 3 Maintenance
3	Wind break forest	Between farmland and sand dunes	Labor demanding High consumption of water Good ecological & economic benefits	Relatively cheap More effort to maintain	4 Effectiveness 4 Durability 2 Maintenance
4	Enclosure for grazing land and forest	Desert grassland Forest area	Increasing biodiversity Few labor demanding	Cheap Easy to maintenance	4 Effectiveness 4 Maintenance
5	Air seeding for grazing land and afforestation	Dissected loess areas Desert grazing land	Must have aircraft Relatively high concentration of rainfall Efficient for making grazing land and afforestation	Cheap in large area Low labor cost	4 Effectiveness 4 Durability 3 Maintenance
6	Blocking in front and pulling from behind	Dune chains	Labor demanding Reduce sand blown off Stabilizing mobile dune	Relatively expensive	4 Effectiveness 4 Durability 3 Maintenance
7	Grass pallisade to block wind and sand and to create pasture	Pasture land	Labor demanding	More effort to maintain	4 Effectiveness 3 Durability 2 Maintenance

8	Integrated management of small watershed with planting	Loess areas	Labor demanding Can cause blow out Long life High social value as it provides cash to local people	Relatively expensive More effort to maintain	4 Effectiveness 4 Durability 2 Maintenance
9	Combating soil secondary salinization with vegetation	Mis-managed irrigation areas Lower reach of river	Labor demanding Few species Improving soil	Costly More effort to maintain	2 Effectiveness 4 Durability 2 Maintenance
10	Combating industrial-mining induced desertification with vegetation	Mining area	Labor demanding High consumption of water Good ecological & economic benefits	More effort to maintain Costly	2 Effectiveness 4 Durability 2 Maintenance
	Engineering methods				
11	Clay sand barriers	2/3 of leeward side of mobile dunes from bottom	Must have clay Labor demanding Preventing rain water from infiltration (crust on surface) Long life	Costly	4 Effectiveness 4 Durability 4 Maintenance
12	Straw checkerboard	2/3 of leeward side of mobile dunes from bottom	Must have local supply of straw Labor demanding short life (2–4 year)	Cheap Low labor cost because of low opportunity cost of rural labor	4 Effectiveness 2 Durability 3 Maintenance
	Engineering measures combining with biological methods				
13	Straw or clay sand barriers combining with vegetation	2/3 of leeward side of mobile dunes from bottom	Must have local supply Labor demanding	Relatively cheap Easy to maintenance	5 Effectiveness 5 Durability 4 Maintenance

(continued)

Table 18.1 (continued)

No.	Technique/methods	Sites where applicable	Limitations/benefits	Relative cost effectiveness	Overall rating
14	Building farmland by leveling sand dune with water	Sand dune	Must have water Less Labor demanding Good results	Cheap Easy to maintenance	5 Effectiveness 4 Durability 4 Maintenance
15	Building water conservation project, reclaiming barren land, and improving soil to form new oases	Intermountain basins surrounded by snow-capped peaks	Must have water Labor demanding Long life High social value as it provides cash to local people	Relatively expensive Low labor cost because of low opportunity cost of rural labor	4 Effectiveness 4 Durability 3 Maintenance
	Chemical methods				
16	Covering sand dune with pitch or making sand barren with asphalt felt	Sand dune	Must have chemical materials Labor demanding Changing soil surface Long life	Expensive Easy to maintenance	4 Effectiveness 4 Durability 4 Maintenance
17	Using some chemical materials (such as plastic film, dry water or soil moisture protector) to protect or supply water for afforestation	Arid areas	Must have chemical materials Labor demanding short life Good results	Expensive	4 Effectiveness 1 Durability 2 Maintenance

The second action relates to efforts by the government and the international donor community, UN agencies like FAO UNDP and UNEP etc. to plan and implement projects in the affected regions of Iran. Through efforts by the national agencies and assistance from the donor community the following has been achieved:

- Land survey of 65 million hectares of rangelands throughout the country
- Formulation of range management plans for 20 million hectares
- Elimination of one million animal units dependent on rangelands through the implementation of a national plan for the management of the arid and semi-arid regions of the Country
- Preparation of large-scale maps of the arid and semi-arid areas using RS and GIS
- Preparation of a 1:250,000 scale map of vegetation cover
- Development of a meteorological and early warning system

3.2 Soil and Water Conservation Activities

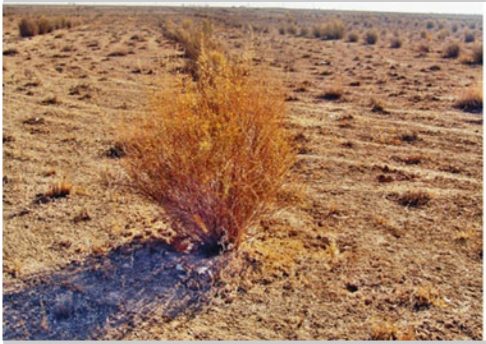
UNDP and the UNHCR sponsored a large scale project in South Khorasan to revegetate land denuded during the occupation of the area by Afghan refugees. The project provided on the job training to the refugees and skills were learned in plant propagation, nursery establishment and nursery practice as well as techniques for replanting large areas. IFAD and UNHCR provided follow-up and extended the successful outcomes derived from the earlier project. Altogether over 50,000 ha was revegetated (Figs. 18.5 and 18.6).

Box 18.1: Successful Control of Dust in the Meighan Desert, Markazi Province

Meighan Desert occupies 5,000 ha and is located about 20 km north of Arak city. Its watershed covers more than 54,000 ha. It is the bed of an old dried up lake and was a major source of dust. Frequent dust storms and shifting sands were extremely damaging to cropland, and the environment and impacted roads and residential zones. In 1991 an ambitious plan was begun to create a green zone around the central basin covering 12,000 ha. Identification of the critical wind erosion center was the first step. *Nitraria schoberi*, a pre-adapted indigenous plant (see Fig. 18.6), was used to stabilize dunes and *Atriplex canescens* was planted in rows to provide a wind break and "roughness element" to reduce entrainment of dust and also provide protection that allowed regeneration of natural vegetation from the seed bank in the soil. The photos show details of the project site in both Farsi and in English and the value of plantations of *Atriplex canescens* that can provide a windbreak and allow regeneration of perennials from seed banks in the soil. Outside

(continued)

Box 18.1 (continued)
the 'greenzone' but within the watershed, other soil and water conservation works were completed, including contour furrowing of 15,729 ha, seeding of 26,553 ha and transplanting seedlings to 17,980 ha.



The following is a list of the major soil and water conservation activities carried out in Iran over the 10 years ending 2010.

- Stabilization of 2.1 million hectares of shifting sand dunes through man-made plantations.
- Formulation of the national plan for natural resources management in the desert areas
- Identification of wind erosion foci
- Formulation of 9 Mha of anti-desertification plans
- Study on 65 million hectares of catchments basins throughout Iran
- Implementing watershed management projects in 14.2 Mha of watersheds
- Sedimentation reduction of up to 23 million cubic meters in watersheds
- Recharging water- tables to an annual volume of 1.4 billion cubic meters

Specific Projects that have been successfully implemented include:

- Formulation and implementation of the Carbon Sequestration Project in Southern Khorasan Province in collaboration with UNDP/GEF
- Implementation of an Integrated Range Improvement Program in Zarand- Saveh.
- Implementation of South Khorasan Rangeland Rehabilitation and Refugee Income Generation Project (IFAD/UNHCR)
- Conducting Sustainable Management of Land and Water Resources(UNDP/FAO)
- The Study on Watershed Management Plan for the Karoon River, (JICA)
- Alternative Range and Pasture Management Methods for the Protection of Native Plant Species in Agro-Pastoral Societies of North West Zagros (Fig. 18.7)

Fig. 18.5 There are large tracts of denuded sandy land. Overgrazing has led to formation of unstable dunes that threaten roads, railways and settlements

Fig. 18.6 The psammophytic plant *Nitraria schoberi* can be used to stabilize moving sand

Fig. 18.7 Small dams allow water harvesting and assist in flood mitigation in an upland catchment of Atrak river

Three ongoing joint UNDP-FRWO projects (MENARID, Carbon Sequestration and Sustainable Management of Land and Water Resources) are aiming at and are rooted in institutional strengthening, integrated planning and coordination, and participatory approaches. The current Development Plan is aiming at covering 8 Mha of land by end of the Plan period through implementation of modern watershed development approaches. UNDP is supporting the process through the above- mentioned projects.

3.2.1 Past Efforts

The first committee for soil and water conservation was established in 1958 in collaboration with FAO. This committee decided some measures to stabilize shifting sand dunes and in 1959 a small scale research project was put into implementation in an area of 10 ha in Khuzestan province. In 1965 another sand dune fixation project was carried out in an area of 100 ha in the south part of Khorasan.

Because of successful results obtained from this UNDP-FRWO project, it was immediately extended to other parts of the country, facing the same problems. These projects mostly consist of (a) Biological operations; (b) Physico-chemical activities. Biological includes plantation of seedlings and cuttings, seeding, and enforcement of closures. *Haloxylon persicum, H.ammodendron, Atriplex lentiformis,*

Fig. 18.8 Biological measures involving planting of trees and shrubs for rehabilitation of degraded lands

A. canescens, Calligonum spp., Artemisia spp., Tamarix hispida, T. katchy, Robinia pseudo acacia, Eucalyptus camaldulensis, and some other drought tolerant species were used for sand dune fixation and desert rehabilitation (Fig. 18.8).

Physico-chemical operations (for temporary stabilization of unstable soils and sand dunes) including oil mulch spraying. Spraying dunes with petroleum-derived mulch has been used with success in some areas. Wind breaks, checkerboards, etc., which provide suitable conditions for plantation and/or natural regeneration (see Figs. 17.7 and 17.8 in Chap. 17).

Since the beginning of the sand dune fixation project up to now, more than one million hectares (Mha) has been brought under control. Presently, the average biological production in the reclaimed land is 200 kg and total annual production amounts to 200,000 t. Of the 8 Mha that have been designated for rehabilitation and reclamation programs; 4 Mha are now in the process of implementation. The program for short to medium-term (up to 2025) is to manage 11 Mha of desert and desertified area by the government and 12 Mha by private and social activities with cooperation of government by technical and fundamental aid and financial support of banks. The rehabilitators will be the owners of the reclaimed areas –according to the new law.

Community involvement is important and participatory approaches are the key. The National Action Plan to combat desertification national plan to combat desertification was ratified in 2004 and this placed an emphasis on community participation (Figs. 18.9 and 18.10).

Fig. 18.9 Participatory approaches are a way to involve the local land users in project planning, implementation and monitoring

Fig. 18.10 Community participation in tree planting and other revegetation efforts is a way to ensure the sustainability of projects

4 Desertification Control Research Activities

Through more than 30 years of Iranian desert research activities, many research projects have been carried out for solving desert problems and to introduce and improve measures for control desertification.

Field experiments were conducted by Rangavar et al. (2009) at Sanganeh Research Station in North-east Iran to assess runoff production, soil accumulated moisture and develop a semi empirical model to determine the best plant row spacing for reclamation and optimum production of degraded rangelands under natural precipitation. Runoff production and soil accumulated moisture were determined in 80 experimental plots on different combination of soil type, vegetation cover and slope gradient, during autumn, winter and spring precipitations during 1996–2005. Results from 90 precipitation events with various magnitude and intensity indicated that, accumulated soil moisture was not significant in September to November period and the amount of evapotranspiration was more than precipitation up to six fold. The average of soil moisture accumulation, evapotranspiration and surface runoff in winter were calculated around 64, 33 and 3 % of precipitation, respectively. In spring, the average of evapotranspiration, infiltration and runoff were 62, 36 and 2 % of the rainfalls, respectively. The values for soil moisture accumulation and surface runoff on the experimental plots make it possible to estimate the potential deficit of moisture and assess the water supply of the plant. Experimental data were used to develop a semi-empirical model to determine the best plant row spacing for optimum production and water requirement of pastures.

The most important result of three decades of desert research in Iran can be summarized as the concept of flood water utilization which is the key for combating desertification in most of the arid environments (Kowsar 1992; Rangavar et al. 2009).

Box 18.2: Pilot Project of Flood Spreading System

Pilot area is a 6,000 ha sandy expanse located on the alluvial fan of the Bisheh Zard river in Gareh Bygone plain. The mean annual precipitation is about 150 mm, 90 % of which occurs between October and April. The mean annual evapotranspiration is estimated to be 2,860 mm. There is a hot summer and a cold winter.

Eight flood water spreading systems, ranging from 25 to 365 ha in area with a total coverage of 1,365 ha, were designed and constructed between 1983 and 1987 on the intermediate zone of alluvial fan (see sketch map).

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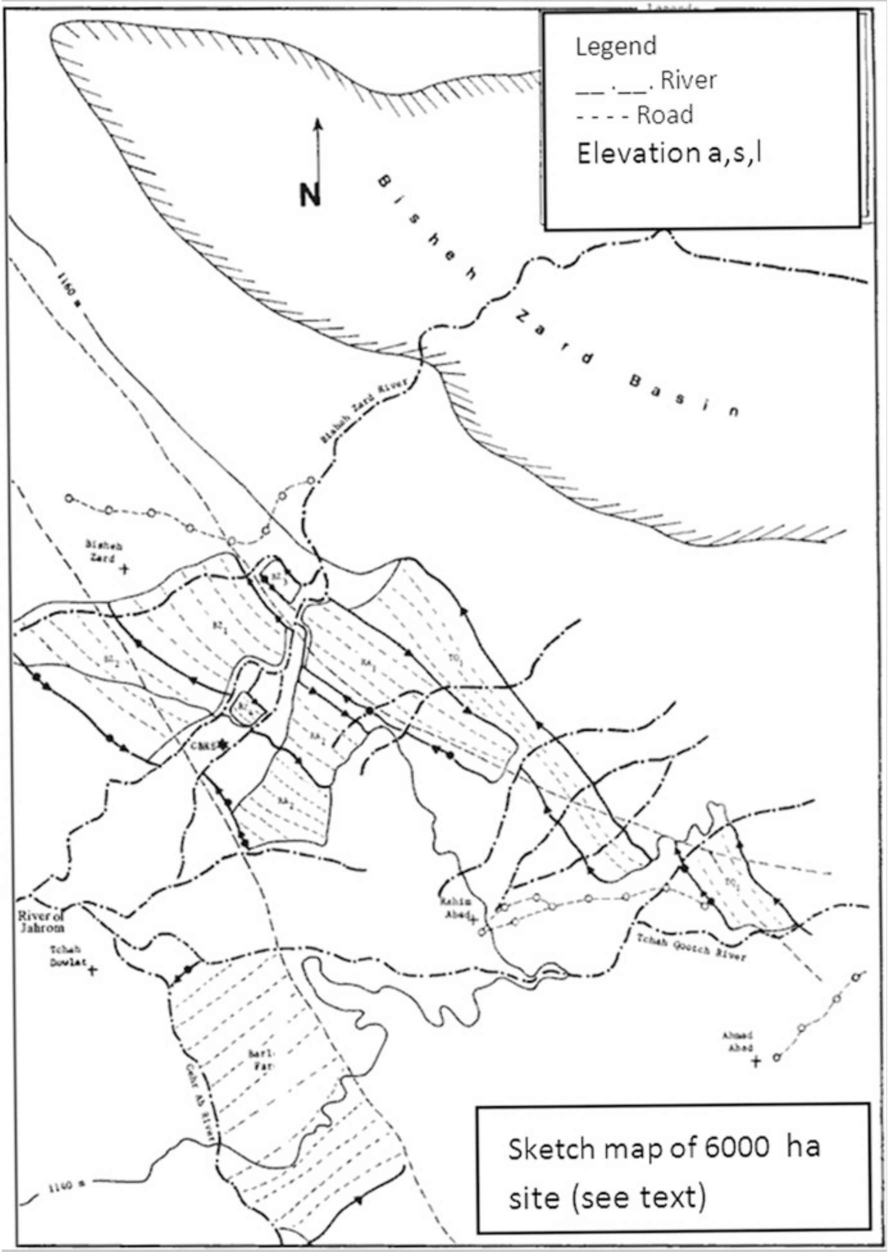
Box 18.2 (continued)



(continued)

Box 18.2 (continued)

The procedures used are a modification of those outlined by Quilty (1972a, b). The systems serve as sedimentation basins and infiltration ponds for the artificial recharge of ground-water; and also as experimental plots for investigation range improvement, moving sand stabilization, afforestation (Kowsar 1992). Transformation of a desolate, sandy expanse into a verdant horizon is the most obvious result of the flood water spreading pilot effort (Fig. 18.11).

The expansion of irrigated fields in what was previously a water-short area is convincing evidence of the effectiveness of the measure. Increasing the amount of groundwater, decreasing of its salinity, prevention the flood hazards, is the other benefits. From Jan. 1983 through Feb. 1988 there were 21 floods of varying intensity and duration. It is estimated that a total of 38 million m^3 diverted by the system and 25 million m^3 were directed to reaching the groundwater under unimproved conditions, less than 10 % of precipitation finds its way into the groundwater aquifers. In pilot area, grazing capacity has become ten times and yield of farmlands reaches to two times more than the past. (Summary of work reported by M. Pakparvar).

Fig. 18.11 Flood water spreading and utilization has been developed to a high level

4.1 New Fields of Research

As well as continuing previous activities, there are some other fields of desert research as follows:

1. Assessment and monitoring of desertification. This activity is performing as a national and integrated project using remotely sensed data and GIS, which will be completed and updated by field investigations. In general there is an upward trend of desertification in the country, but real data are not yet available. As more advanced sensing and evaluation techniques (Shafie et al. 2012) are applied to the problem the picture will be become clearer and provide government with focus areas for urgent attention as well as an aid in the development of an action plan to combat desertification and land degradation.
2. Use of new techniques of plant breeding in order to produce the most tolerant generation of desert plants and salt tolerant plants. Biosaline agriculture is a possibility (see also Toderich et al., Chap. 13).
3. Improvement and modification of useful and simple to use of water saving methods. For example there is a great project for utilization of clay pipes after special processing in order to use as sub ground irrigation tools.
4. Ascertain the origin of sand dunes. The most effective sand dune fixation activity could be done in the area which is origin of the blown sands. Wind direction and speed analysis, study of sand morphology, finger printing of mineral composition; are the technical ways for recognition the origin of sand dunes.

4.2 Educational Programs to Strengthen Institutional and Technical Capacity

Over the past decades Iranian universities have strengthened their teaching and research in the areas of Natural Resource management, especially on watershed management and rangeland management including rangeland/livestock relationships.

4.2.1 Watershed Management

The final goal of the watershed management departments is to apply integrated management of watershed in all catchments throughout the whole country in order to reduce water loss, soil erosion and foster rational use land, water and other natural resources. The specific objectives are:

– Expanding the knowledge and attitude of people about watershed management activities.
– Implement projects to arrest and reverse land degradation based on sound principles and good design

– Developing scientific and administrative capacity within implementing organizations about watershed management plans in the country.
– Ensure active participation by land users and other relevant stakeholders in the planning, decision-making and execution of soil and water conservation activities within catchments
– Introducing watershed management principles and practices to the responsible authorities in Iran and stress its importance and priority in execution of integrated watershed management in the pursuit of economically viable agriculture and the survival of socio-economic life of villages. And also emphasize the necessity of allocating enough facilities and financial credits for the matter.
– Developing rational land use by farmers and others by Increasing awareness and providing training on sustainable agricultural practices, crop rotation, minimum tillage, conservation agriculture, improved livestock husbandry and animal health etc.
– Providing essential laws and regulations as executive guarantees for developing and performing watershed management activities.
– Provide sound advice on which to base integrated watershed management plans as foundation for participatory development programs.
– Providing and organizing the elements of natural resources and agricultural systems information exchange.
– Applying long-term and short-term training courses in the country and abroad in order to have active experts and staff.
– Providing comprehensive studies and serious research in the watershed management plans.

4.2.2 Rangeland Management

There is a professional Society for Rangeland Management and a regular scientific journal (*Journal Rangeland Science*). Iran is also hosting one of the six Thematic Program Networks (TPNs) under the UNCCD.

Box 18.3: Iran as Host to the UNCCD TPN3

The TPN3 was launched in Yazd in 2008. The network has the objective of re-establishing sustainable systems for managing rangelands and livestock production in the rangelands in an economically feasible and socially equitable manner. The core sub-program areas have been endorsed, namely: capacity building on new approaches to rangeland management, indigenous

(continued)

Box 18.3 (continued)
knowledge, participatory approaches for management of rangelands, comparative and other suitable methods for sand dune fixation.

The core objective of TPN3 is:

The creation, collection and circulation of information and building up of capacity to assist in re-establishing sustainable systems for managing rangelands and livestock production in an economic and socially equitable manner in participating countries (Oman, Saudi Arabia and Qatar).

Its specific objectives are to:

- develop suitable range management methods through action research, and to promote and monitor the continuing wise and sustainable use of Asia's rangelands;
- standardize the database and procedures for managing rangelands, fixing sand dunes and combating desertification, and establish a network capable of integrating this information at national and regional level;
- strengthen institutional and local capacity in the procedures and skills of sustainable range management and sand dune fixation, and in the collection, management and exchange of information; and
- integrate indigenous knowledge

TPN3 would further:

- promote partnerships within, between and among participating members and countries;
- integrate contributions from institutions and professionals, as well as from governmental, non-governmental and community actors;
- be participatory.

5 Conclusions

Iran has areas vulnerable to desertification due to extensive areas of drylands and increasing population pressure on land and water resources. Over-grazing of rangelands is a particular problem. Initially desertification was combated mainly at the local level and involved dune stabilization measures, especially the use of oil mulch, re-vegetation and windbreaks. Insufficient technical planning in the early years has led to changed approaches to plant densities and species diversity in plantations, and increased on-going management of existing plantations. Since the late 1980s forage and crop production has increased in areas where runoff control techniques are practiced. The social and economic aspects of anti-desertification programs have assisted in poverty reduction by providing off-season employment in rural areas. In 2004 a national plan to combat desertification was ratified and this placed an emphasis on community participation. Continuing challenges include managing existing desertified areas as well as taking into account potential future problems associated with rapidly depleting groundwater supplies and a predicted reduction in the plant growth period accompanying climate change.

Improper land use and prolonged drought are the principal agents of desertification. Reduced groundwater discharge, a variation of drought, is mainly due to over-exploitation of a limited resource; hence, it is partly man-made; therefore, humans have the power to control desertification through proper utilization of land and water. This may be partially achieved by harnessing the flash floods common to most deserts. Floodwater spreading is the key to desertification control in many parts of the world.

Practical measures to arrest and reverse land degradation have been developed over the past 25 years. Sand dune fixation by mechanical, chemical and biological means is now well established technology. Control of soil erosion by water is serious even in drylands where rainfall intensity is often high and sediments are easily transported. Remedial measures have been perfected and replicated throughout watersheds over the entire country. Proven approaches to land degradation control are numerous, the necessity to apply them is strong, the technical capability is high and finance is not such a limiting factor. The future outlook is optimistic.

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Chapter 19
Land Degradation in the Sultanate of Oman: Reasons and Intervention Measures

H. Al-Hashmi

Synopsis The Sultanate of Oman is a desert country with a large part of its territory classified as arid or hyper-arid. Desertification *per se* probably does not occur because hyper-arid regions are excluded from the UN definition of regions where desertification is said to occur. But desert encroachment and land degradation in its many forms are a problem and this chapter examines the situation in Oman and the steps taken to remedy and reverse the situation.

Key Points

- The Sultanate of Oman is located on the Arabian Peninsular which is classified according to the World Atlas of Desertification as mostly Hyper-arid and Arid in parts – 95 % of Oman is either climatic desert or more than moderately affected by land degradation. The conservation and protection of the environment of Oman, is the major component of this National Conservation Strategy to safeguard the welfare of the coming generations of people of Oman. It is seen as a pillar of national development because the achievement of the socio-economic development depends on the existence of suitable environment conditions that lead to attaining the balance between the people's welfare and conservation of the natural resources.
- There are 2.3 million hectares of land suitable for agricultural production in the Sultanate of Oman. However, the future exploitation of these lands depends, to a large extent, on water availability. The area under rangelands in the Sultanate of Oman amounts to 172,625 km^2 (17,262,500 ha). The productivity of these lands is estimated at 0.2 tonnes/ha (Agricultural and Fisheries Development in the Sultanate of Oman 2005). This means that the rangeland resources provide some

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3.45 million tonnes of feed/year. There are 647,250 TLU (Tropical Livestock Unit) in the Sultanate of Oman. The livestock inventory in 2005 was comprised of 117,000 camels, 351,000 sheep and 1,557,000 goats. Camels are widely kept in the Sultanate. They are mostly managed extensively although some are kept in pens.

Keywords Desert development • Sustainable development • Water • Agriculture • Feed balance • Livestock inventory • Camel • Desert encroachment

1 Introduction

1.1 Basic Geographical Features

The Sultanate of Oman occupies the south-eastern corner of Arabian Peninsular between the latitudes 16°, 40′ East, it has a coastline extending almost 1,700 km from the straits of Harmuz in the North to the border of the Republic of Yemen. It is bounded by the Arabian Sea, the Sultanate borders with Saudi Arabia and the United Arab Emirates in the West and with the Republic of Yemen in the South (Fig. 19.1). The total Area of the Sultanate is approximately 300,000 km^2 and it is the third largest country in the Arabian Peninsular.

Fig. 19.1 The Sultanate of Oman that lies adjacent to the Arabian Sea and borders on Saudi Arabia, UAE, and Yemen

The population in 2011 was estimated to be about three million, including about 500,000 foreign nationals. About 73 % of the population is urbanized but most of the population is engaged in agriculture, trade, fisheries, traditional industries and handicrafts. The estimated average annual population growth, is 3.5 % (including inward migration) but the death rate is 3.2 %.

1.2 Climate

The climate varies from one area to another. It is hot and humid in the coastal areas in summer; and hot and dry in the interior, with the exception of higher mountains which enjoy a moderate climate throughout the year. Generally, the Sultanate has little and regular rain, though heavy rains some time erratic rains fall from time to time. An exception is the southern part of the Sultanate where heavy regular monsoon rains fall between June and October.

Annual mean temperature ranges between 17.8 and 28.9 °C. Due to the effect of high altitude, mountains like Jabal Lakhdar in the north and Jabal Al Qairoon Hairiti in the south have the lowest average annual mean temperatures, 17.8 and 21.6 °C respectively. Salalah and Thumrait also have slightly lower mean temperatures than the national average, which is 26.3 °C, because they are affected by the southwesterly monsoon winds, which reduce the temperature of the southern region during summer. In other areas mean annual temperatures range from 26.3 to 28.9 °C. In general, the annual mean temperature increases from east to west. The hottest months are June and July, and monthly mean maximum temperatures range from 30.7 °C in Saiq to 46.1 °C in Fahud. All over the country the coldest month is January, with monthly mean minimum temperatures ranging from 9.4 °C in Saiq to 24.0 °C in Mina Raysut. Temperatures below zero are only recorded in Saiq where they occur every year (record minimum temperature of −3.6 °C).

Precipitation is generally low and irregular. Only the Dhofar Mountains, in the southern region, and the Hajar Mountains have regular rainy seasons with substantial precipitation. Heavy rains can occur, sometimes delivering all the precipitation of the year in one single shower, causing violent floods. Mean annual rainfall is less than 50 mm in the interior regions, covering two-thirds of the country, and is around 100 mm in coastal areas. In the Hajar mountains rainfall ranges between 100 mm to about 300 mm. Parts of the Dhofar Mountains, influenced by the monsoon, receive between 200 and 260 mm of rainfall. During the monsoon season, mist and fog are very common in this area, and may contribute significant amounts of moisture to the vegetation. During September to November, very little precipitation is observed in the country. Monthly mean relative humidity is highest in coastal areas where it ranges from 50 to 90 %. The interior areas are much drier and have mean relative humidity (RH) of less than 50 % for 4–5 consecutive months. In these areas the absolute minimum RH can be as low as 1 or 2 %.

1.3 Physiographic Regions

The Sultanate consists of Plains, Wadis and Mountains. The most important area is the plain overlooking the Gulf of Oman and the Arabian Sea with an Area of 9,000 km^2 (3 % of the total) while Mountains Ranges occupy about 45,000 km^2 (15 %). The remaining area is simply sand and desert which includes part of Ar-rub Al-Khali (empty quarter) occupying 246,000 km^2 (82 %) of the total areas. According to the general soil map of Oman (MAF 1990) Oman is divided into eleven Physiographic regions:

1.3.1 Arid Mountains

These are encountered mostly in the Hajar Mountains, in northern Oman, including the Musandam peninsula. They also occur to a much smaller extent in islands such as Masirah and Al-Halanyatt These Mountains are mostly steep and barren formations of igneous and sedimentary rocks.

The Hajar mountains range stretches northwest southeast, along the Gulf of Oman, over about 700 km from Ras-Al-Hadd to Musandam. Its width varies between about 30–70 km.

Bare rock outcrop and very shallow soils are dominant on sloping terrain, whereas very gravelly soils occur in valleys and alluvial fans. With summits nearing 3,000 m above sea level in Jabal Lakhdar, the Hajar mountains intercept moist air masses, hence receiving relatively higher precipitation than surrounding areas. A dense network of wadis conveys drainage water north to the Batinah plain, and south to the interior of Oman.

A large number of scattered oases, mostly using falaj irrigation systems, tap local springs or wadis underflow, to grow mostly date palm, limes, alfalfa and vegetables.

1.3.2 Monsoon-Affected Mountains and Plateaus

This kind of landscape occurs only in two separate areas, both in the Dhofar region. One is north of Salalah, the other, along Rakhyut coast.

These areas are strongly dissected. A woody vegetation predominates on steep slopes and gullies, whereas grass and bushes, under heavy grazing, cover most of the relatively flat areas.

Soils are generally shallow in the grazed areas, suggesting that soil erosion is very active in the rangelands. Wooded slopes, protected from erosion by trees and bushes, generally have moderately deep soils.

Rainfed cultivation of beans and sorghum is done by some Jabali in very tiny plots during the monsoon.

1.3.3 The Arid Dhofar Plateau

The Dhofar plateau, which is gently sloping towards the north, is dissected by numerous wadis cutting deep and narrow incisions. Most of the area consists of sedimentary rocks.

Soils are mostly shallow and the meager natural vegetation is under heavy grazing.

1.3.4 Accumulation Plains

There are five accumulation plains in Oman: the Batinah plain, the Northern interior plain, the Sawqirah plain, the Dhofar piedmont and the Salalah plain.

All these plains are bajadas formed by the accumulation of three generations of alluvial fans and terraces. The Sawqirah plain differs somewhat from the other accumulation plains in that the rock floor outcrops in sizeable areas.

The soils are generally deep and very gravelly to extremely gravelly in all these accumulation plains. In the Salalah plain the soils are not gypsiferous, whereas gypsum accumulations occur in most soils of the other accumulation plains. The quantity of gypsum and the degree of cementation tend to increase with the age of the soils.

Cultivation is generally found in the lower alluvial terraces wherever adequate water resources exist. Most of these cultivated areas are in the Northern interior plain and the Batinah, because water resources are limited in the other accumulation plains.

Date palm, limes, alfalfa and vegetables are the main cultivated crops. Falaj systems are the main source of irrigation water, but wells are expanding very quickly in and around the oases.

1.3.5 Accumulation/Denudation Plains

These are old accumulation plains where dissection of the landscape by stream erosion has exposed extensive areas of rock outcrop.

The Mirbat plain is mostly rocky, but two levels of alluvial terraces were found in its western part. They are mostly formed of loamy gravelly deposits.

The Northeastern plain in the Sharqiya region is less rocky, but the high alluvial terraces are extremely dissected. Soils are generally gypsiferous, but many of them have very strong salt accumulations. These salts seem to be deposited by droplets of seawater brought by winds.

Cultivation is very limited because of scarce water resources. Datepalm and alfalfa are the main crops.

1.3.6 Coastal Alluvial Plains

There are only two such alluvial plains in the Batinah and Salalah areas. Before reaching the sea the wadis, originating in the nearby mountains, become braided and deposit their load of sand and finer particles in depressions behind coastal dunes before infiltrating into shallow aquifers.

These coastal plains have some of the best soils of the country and relatively important water resources.

Nearly half the cultivated area in Oman is in the Batinah coastal plain. Excessive expansion of the cultivated land has led to seawater intrusion and salinization of the groundwater and the soils. Crops grown in the Batinah include datepalm, limes, mangoes, alfalfa, rhodes-grass, and a variety of vegetables and minor fruit trees.

In the Salalah coastal plain, the main crops are banana, coconut, papaya, vegetables and other minor crops.

1.3.7 Sabkha-Dunes-Rock Outcrop Complex

This landscape occurs extensively in Al Huqf area and in the Eastern coastal plain in the Sharqiya region. Hills of rock outcrop alternate with saline basins and sand dunes. Tidal flats are extensive along the coast.

Cultivation is very scarce due to the lack of suitable water resources. It is interesting to note that this area may have some potential for fish farming.

1.3.8 The Eastern Pediplain

It is a nearly level monotonous rock plain made of hard carbonate rocks that resist erosion. There is a large number of small depressions caused by dissolution of the carbonates, under a past, moister climate. This landform is deeply incised by wadis near the seacoast.

Soils are generally very shallow and contain secondary lime. Cultivation is very scarce because of the lack of suitable water resources and soils.

1.3.9 The Western Pediplain

It is gently undulated and more dissected by streams. Sulfate rocks are more extensive in this area, leading to the concentration of gypsum in the soils, which are generally moderately deep to shallow to a gypsum pan and to bedrock.

Cultivation is found in some areas like Dawka where good groundwater is available. Rhodes grass, alfalfa and vegetables are the main crops.

1.3.10 Umm-As-Samim Sabkha

This is a large flooded depression collecting drainage waters from the western part of the Northern interior plain.

Soils and groundwater are extremely saline, hence preventing any cultivation

1.3.11 Sand Dune Areas

These are large areas of sand dunes. They occur extensively in the western part of the country in the Rub Al Khali and the Wahiba sands area.

Cultivation is very scarce because of unsuitable soils and sand blowing. Grazing is widespread, especially in semi-fixed dunes where a relatively dense bush and tree cover may occur.

2 Causes of Desertification

2.1 Physical Factors

On the basis of the climate and physiographical features of the Oman, the cause of desertification are as follow:

(i) The climate, which characterized, by a low and erratic rainfall, high temperatures, and occasional storm leading to the sand drifts, and soil erosion
(ii) Water scarcity, which considers the most critical resource in the Sultanate, at Present and future (due to water misuse in agriculture, over exploitation of aquifers which led to severe salination of the cultivated lands in Batinah Plains).
(iii) Sand drifting, which represent serious problems over areas adjacent to Wahiba Sands and in the plains and wadis of Dakhliya (interior), Wusta, and Southern Regions. The advance of Wahiba Sand dunes are hazardous to roads and other installations near them. No information about the agricultural and grazing areas effected with the sand burial.
(iv) Overgrazing, which is common all over the Sultanate, and more severe in the Southern Region.
(v) Expatriate labor, in the agriculture sector, which is considered to be the main obstacle for agricultural development.
(vi) Over-pumping of water which leads to salination of groundwater particularly in the Batinah Coast.

2.2 Socio-Economic Factors

The evaluation of socio-economic factors effecting desertification process in Oman will be limited and difficult however the following factors contributed to the desertification process can be summarized as follow:-

(i) The type of farming practiced in the Sultanate, which characterized by small holdings – operated traditionally becomes profitable only when cultivated to high water consuming crops i.e. vegetables and forage crops.
(ii) Employment in agriculture represents one of the major constraints for agricultural development. It was felt that young Omanis show unwillingness to work in agriculture.
(iii) It is known that the type of farming, (Traditional vs Modern) is of crucial importance to the Sultanate. Reforms leading to the reduction of water use (sprinkle and drip irrigation) to increase of yields, and hence, leading to increased net profitability of agricultural lands can help to combat desertification caused by traditional subsistence farming. The improvement will however need skilled labor, active extension service, financial supporting system and organized marketing of products.
(iv) The zero value of water has encouraged farmers to the extent of overusing of this free but scarce resource, and lead to the increase of salinization.

3 Efforts to Combat Land Degradation and Implement Conservation Measures

The efforts exerted by the Government to combat land degradation can be summarized in the following way:

1. Preparation of the National Conservation strategy of Oman, which laid the basis for future environmental policies. The National Conservation strategy (NCS) pointed out that the sectoral and regional studies by the Ministry of Agriculture and fisheries resources, Housing, Regional Municipalities and Environment and the Governorate of Dhofar have drawn attention to growing problem of desertification. Of 25 projects suggested in the NCS, 11 have more or less strong connection with Desertification control. This indicates not only the advanced nature of the growing problem of desertification but also the magnitude of the problem.
2. Regional studies on soil conservation and land uses.
3. Integrated development of plains adjacent to the Eastern Region and Eastern fringes of the Wahiba Sands.
4. Integrated development of the Najd area in Dhofar.
5. Efforts in the fields of afforestation and protection of forests.

6. Reclamation of marginal lands in some areas.
7. Fields management of irrigation water.
8. Studies to associate arable lands with areas existing and expected underground water potential.
9. Study of soil contamination resulting from the uses of agricultural lands.
10. Preparation of plans for the survey and development of Regional water resources.
11. Organization of grazing in the mountains of Dhofar.
12. Establishment of gardens, parks, and nature reserves all over the Sultanate.
13. Preparation of the National Plan to combat Desertification (NPCD).
14. Planting drought and salinity-resistant plant to expand vegetational cover in the affected areas,
15. Use of treated sewage water in irrigation as an important source of water for agriculture.
16. Study of water resources development and preparation of National Water Master Plan (NWMP), and preparation of Master plan for ground water pollution protection (MPGWPP). See also Al-Balooshi ASS (2003) for an overview.

4 The National Plan of Action to Combat Desertification (NPACD)

The plan (NPACD) came as a result of a joint cooperation between the Sultanate and the United Nation Environment Program (UNEP), the Economic and Social commission of Western Asia (ESCWA) and the food and agriculture organization (FAO). The (NPACD) was prepared in 1993, and the content of the plan can be summarized in the following:

1. Inventory of Natural resources of the Sultanate.
2. Socio-economic setting of the Sultanate.
3. The status of desertification in the Sultanate and its causes.
4. Overview of the Sultanate's efforts to combat desertification.
5. The (NPACD) proposed 24 priority projects to control desertification and minimize its risks, the projects are not only supported by relating them to the recommendation of UN conference on desertification plan of action, but also to the revised set of recommendation presented in the report of the executive Director of UNEP to the UN conference and development 1992.

Finally, while the Sultanate proceeds in implementing the plans aimed at the sound management of its lands and water resources, in addition to combat desertification and increasing the cultivated areas within its available potentials; it is evident that lack of financial and technical support necessary to combat desertification at the local, regional and international levels, will subject the plans and efforts to be inefficient and non-sustainable. And by accession to the U.N. convention to combat desertification in those countries experience draught and/or desertification, particularly in Africa, the Sultanate intends to obtain the following:

- Financial and technical assistance provided by the international organizations and developed countries to implement desertification combating programs and alleviating the impact of drought.
- Technical advice and technologies required to implement the (UNCCD).
- Assistance in training Omani technical staff, upgrading and qualifying them to implement desertification combating programs and to use necessary technologies i.e. (NDVI) technique, and remote sensing methodology.

It is worth mentioning, that the Sultanate is an active member of the "steering committee of the desertification combating and green areas increasing program of the Arab world" of the technical secretariat of the council of Arab Ministers responsible for the Environment. Also, the National Committee to follow up the implementation of UNCCD, was formed under the chairmanship of H.E., the Undersecretary of the Ministry of Regional Municipalities and Environment (MRME) for the Environmental affairs and memberships of the concerned Ministries such as Ministry of Agriculture and Fisheries, Ministry of Water Resources, Ministry of National Economy, Ministry of Communication and Sultan Qaboos University.

The task of this committee is to:

- Follow-up of the implementation of UNCCD
- Coordination of the efforts in prevention of Desertification
- Suggesting priorities and action plans to combat desertification, and allocation of the necessary financial resources to implement such priorities.

5 Strategies and Priorities Established with the Frame Work of Sustainable Development Plans and/or Policies

(a) **National Conservation Strategy** (**NCS**).
This project included the computation resources including lands, water, rangelands, forest, fisheries and wildlife, the present and future levels of demand of these resources and the factors determining their productivity in a sustainable manner have also been in account. The NCS has also provided the opportunity for reviewing the Omani Experiences in development planning and its associated administrative, institutional political and legal frame-works. In brief the (NCS) adds an important dimension to the concerted effort of comprehensive development, which has progressively affected all aspects of life in Oman

(b) **National Plan of Action to combat Desertification in the Sultanate** (**NPACD**).
As mentioned above.

6 Feed Balance Is a Problem

The present feed supplies are estimated to be about 20 % below the needs of cattle. The shortage is most severe in East Qara but is only about 10 % in Qamar. The general situation is worse for the camels and goats because they receive less supplementary feed, which accounts for only 11 % of their needs. The overall feed shortage for them is about 30 % for whole area. It is worse in the West Qara (46 %) than in Qamar (8 %). The population is estimated as 36,386 consisting of 32,157 Omanis and 4,229 expatriates. The estimated zonal distribution is 5,810 in Qamar (4,983 Omanis and 826 expatiates). 15,975 in West Qara (13,952 and 2,023) and 14601 in East Qara (13,222 and 1,379). The majority of the employees are from Bangladesh and India, and undertake the feeds, watering and cleaning for the livestock, with the head of household doing the milking, transport of water and the buying and selling of stock and feed. Hired labor is less common in Qamar than in Qara Fig. 19.2.

Tables 19.1, 19.2, 19.3 and 19.4 set out the key statistics on population, livestock inventories, and feed supply and demand.

7 Case Studies

7.1 Detailed Land Use Study in Jabal Dhofar

The Jabals (Mountains) of Dhofar benefit from the monsoon rainfall, and their natural vegetation is grassland and woodland. The Jabals supported large herds of cattle, camels and goats. Recently, there has been a considerable increase in livestock numbers, and the Jabals are now overstocked and overgrazed. The aim of this study, "conducted and finalized by Travers Morgan (Oman) Ltd, is to develop a detailed land use policy for the area, with particular emphasis on the ecological, environmental, social and economic aspects of the pastoral sector". The survey area stretches from Khadrafi in the West to Hino in the East, and from coast to the desert fringes of the Nejd in the north. The whole of Jabal Al Qara and Qamar and the South-western end of the Jabal Samhan are included. It also includes the Jerbeeb (Coastal Plain) and foot of the main scrap of Jabal Al Qara and the Western Part of Marbat (The land use study in Jabal Dhofar).

The study concluded the following:

The situation in Jabal Dhofar can be seen as the result of changes to an integrated social, economic and ecological system, that used to be none or less in dynamic equilibrium with its physical and biotic environment, but is now been disturbed by external events, such as the rapid economic and infrastructural development since 1990s. The positivity of these social impacts of the development is good education and health services and modern infrastructure one is already in place and others are being continually improved.

Fig. 19.2 There are about 120,000 camels in Oman, mostly they are on the rangelands and rely on sparse desert forage and browse

Table 19.1 Human population by region in Oman

	Qamar	W. Qara	E. Qara	Total
Omani	4,983	13,952	13,222	32,157
Non-Omani	827	2,023	1,379	4,229
Total	5,810	15,975	14,601	36,386

Table 19.2 Estimated livestock number 1994 and 2005

Area	Cattle	Camels	Goats
Qamar	19,700	10,600	14,100
West Qara	56,500	21,300	42,200
East Qara	78,900	12,700	29,200
Survey area total	155,100	44,600	85,400
Excluded urban areas	5,500	300	2,500
Dhofar total	156,900	69,700	142,300
Sultanate total 1994	213,100	98,600	854,100
Sultanate total 2005	n/a	117,000	1,557,000

Table 19.3 Current dry matter balance

	Qamar	W. Qara	E. Qara	Total
Grazing				
Fodder	37	91	104	232
Livestock needs	41	111	153	305
Deficit	4	19	49	73
As % of needs	10	18	32	25
Fodder	33	43	37	113
Livestock needs	35	80	52	167
Deficit	2	37	15	54
As % of needs	8	40	29	32

Table 19.4 Potential dry matter balance

(000/Md/Year)	Qamar	W. Qara	E. Qara	Total
Grazing (cattle)				
Fodder	56	143	154	352
Cattle needs	37	103	153	292
Surplus	19	40	1	60
As % of needs	51	39	1	21
Browse (camels and goats)				
Fodder	48	62	53	163
Camels + goats	39	88	53	180
Surplus (+) shortfall (−)	+9	−26	+1	−17
As % of needs	+22	−27	−1	−9

However these improvements are funded from external sources and not from the investment of surpluses generated from within the local pastoral economy. In contrast to the said welfare improvements, the Jabal economy and its resources base are not thriving. It is possible to interpret the problems as the growing pains of systems adjusting to considerably changed circumstances, which include:

(a) Increased external trade, particularly the importation of goods and services.
(b) The weakening of legal basis for local communal control of grazing.
(c) Improved water supplies, accessible and free to all.
(d) Improved animal health.
(e) Access to non-livestock income.

(f) Access to commercial credit.
(g) Meanwhile the degradation continues, the deterioration will also continue, and possible acceleration and production will fall still further. Eventually the ecosystems will be so damaged that the changes are effectively irreversible over time scale of years and decades. When that happens, the social and economic effects could be as serious as those on the environment.

The study surveyed the range land zones: Qamar Zone (1,020 km^2) Qara zone (1,506 km^2) and East Qarazon 1,266 km^2.

The ecological survey mapped of vegetation zones and overgrazing state of the range-land. The tall mixed grasslands of the moister parts of Jabal and the woodlands on the steep slopes in the same areas are most important zones as range resources. There are 678 km^2 of these grasslands and 622 km^2 of the associated woodland, over 90 % of the vegetation was assessed as overgrazed. In places the grass is removed completely and the ground is bare. Some areas of woodland are heavily over-browsed that the trees are dying, particularly where the livestock are gnawing the bark. There are about 155,000 cattle, 44,500 camels and 85,000 goats in the area. The balance between the feed supplies and the requirements of the livestock has been calculated with the cattle treated separately from goats and camels.

7.2 Pilot Study Project

Pilot study project for the use of modern simulation and interactive modeling technique for design, optimization and viability assessment of efforts to combat land degradation, in Dhofar. The objectives of the project are:-

(a) To make a theoretical pilot study of use of the modern simulation and interactive modeling technique based on the concept of rain forest canopy and natural environmental development.
(b) To establish the project as a resource base for training regional and sub-regional cadres.

Dhofar region was chosen for this project because it presents a good example of ecosystems under the process of degradation, and recent in the making, due to excessive land use and overgrazing at the plateau and the plain on the sea-side of the mountains. At the same time, however, the region receives a reasonable amount of rain during the monsoon period (July – August and September) at the seaside of the mountains, but diminishes drastically at the other side or (*Nejd*), and towards the empty Quarter. The region thus presents an interesting area for applying rehabilitation methodologies e.g. afforestation and appropriate land-use policies and systems. Already a comprehensive study of land use in Dhofar has been accomplished for the Government as mentioned by the firm Travers Morgan in addition to other projects in the National Strategy Plan (NCS), and National Action

Plan to combat Desertification (NAPCD). Such multitude of national rehabilitation and land-use reform plans will need thorough monitoring and assessment studies, firstly to identify the priority problem areas, and secondly, to identify and assess the success of the rehabilitation measures. Computer and satellite technologies have now availed great opportunities for such Pre-evaluations through the studies of the Inter-relations between the General Circulation Models (GCMs) and the changes in terrestrial eco-systems, enabling planners to identify the characteristics of the favorable eco-systems, in what is now known as interactive modeling i.e. interaction of Biosphere with atmosphere.

7.3 Output of the Project

The present plans for the combat of land degradation are no more than plans aiming at a happier mode of co-existence with the desert. At the utmost they may aim at arresting the desert expansion, but through continuously cost involving projects. A permanent economic solution can only be attained if these plans aim at restoration of the ecosystems which are favorable of attracting more precipitation and hence one less drought prone because water from natural rain provides the elements of re-generation and continuity at no cost. Dhofar region has the advantage that it is confined between the Ocean and the Empty Quarter, hence the control volume for the modeling procedures mentioned above can be easily defined. It will be a great accomplishment if the simulation and modeling test prove that it is possible to drive the rain belt over the mountain hump to the Najed, through reconstruction of forest canopy and eco-systems in the plain and plateau favorable for attracting and developing rain.

8 Process in Support of Preparation and Implementation of Action Programs

Following the establishment of the Ministry of Environment in (MOE) 1984, it was entrusted, among other responsibilities with the preparation of National Conservation Strategy (NCS). In June 1989 the MOE organized a seminar for the purpose in collaboration with UNEP and IUCN. It was during the seminar that the new trends calling for the creation of close links between the environment and development, and between the national strategies and the world conservation strategy (WCS), emerged for the first time. The seminar recommendations included the preparation of a comprehensive and balanced National Strategy for environment conservation, covering ecological aspects, nature resource evaluation and definition of the relationship between the environment and development. Two committees were formed for the NCS, first, the permanent committee, by Ministerial Decision, composing undersecretaries from all Ministries, in addition to the heads of Governmental and para-statal authorities, and the second, the technical committee, including selected expert and executives from the Ministries concerned with natural resources and environment. The preparation programs included desk studies, field visits to Ministries, authorities, regional areas, and development projects across all sectors related to the utilization of resources.

There was also a comprehensive questionnaire addressed to all Governmental and Para-statal institution in Arabic and English. The questionnaire consisted of two parts; the first part consisted of general questions to all sectors, while the second part contained sector-specific questions addressed to each sector according to its responsibilities, activities, and to its role in the use of natural resources and in the development process. The NCS team was able to visit most areas of Oman, and was able to get in touch with the realities of natural resources and their patterns of exploitation. The visits also covered agricultural and rangeland projects, fishing harbors and, traditional and modern industries. The team also discussed with producers and businessmen and visited areas of history and heritage. The consultant, has also, together with colleagues in the Ministry and as a part of the program approved, visited four international organizations working in the field of environment and development, namely, IUCN, FAO, UNEP, UNESCO, and the Islamic Republic of Pakistan. After the finalization of the NCS first draft, an International Symposium was held in Sultan Qaboos University, (SQU) with participation of more than 70 experts representing all government para-statal and non-governmental organizations in Oman, in addition to about 30 representatives of regional and international organizations, bilateral agencies, Gulf Cooperation Council (GCC) and other friendly countries and individual cadres and specialists.

8.1 The National Plan of Action to Combat Desertification (NPACD)

The (NPACD) came as a result of cooperative efforts of UNEP, ESCWA, and FAO. The three organizations are involved in a chain of Joint activities with (ESCWA) region member countries to assist individual countries, on request, to prepare their national plans. In this case the job was done in two stages. First, a one man mission prepared Part One the background section which was presented to the Government of Oman in April 1992. This was followed by a three man mission in September of the same year for the preparation of Part Two – The plan program and Projects. *Detailed Land Use Study in Jabal Dhofar*: This study is concentrated on the present state of land use in the mountains of Dhofar, especially the rangeland resources and management aspects of the pastoral sector, and to present the issues, policies and proposals for possible improvement in this sector.

In Phase 1 the current status of physical environment, rangeland resources, the livestock sector, the inhabitants, and the services and facilities available are mapped and analyzed.

Phase 2 consisted of analysis of the data to determine the main issues, constraints and opportunities for the further use of land range resources; examination and constraints: and the practical problems involved in the execution. The general characteristics of the rangelands and livestock as mentioned by the Ministry of Agriculture and Fisheries is as follows:-

The lack of animal food resource (fodder) is considered one of the most serious constraints to livestock development in Oman, especially that the growth rate of the latter has reached an acceptable amount of 3.3 % during the last two decades. The total number of livestock increased from 1,029,227 in 1982 to 1,408,178 in 1993 and to 2,025,000 in 2005. Natural rangelands are considered a major nourishment source for these animals, providing 37 % of dry substances. Next to that is the concentrated processed fodder (31 %) then the irrigated fodder (27 %) and finally the agricultural residues (5 %) The explanatory data of the FAO estimate the capacity of natural range lands and other fodder resources (mentioned above) in the Governorate of Dhofar (the largest natural rangeland area) to be 2.8 times less than the livestock density during the survey. According to that, the rate of overgrazing has reached (65 %) which is extremely high, because once it reaches (30 %) it causes land degradation, accelerated soil erosion and deterioration of rangeland quality and productivity. Due to the significance of the natural rangelands in developing livestock, the Five-Year Development Plans have shown a great interest in a number of projects that aim at stopping desert encroachment and preservation of rangelands. Some of the measures being implemented are:

- Controlling and monitoring grazing in Dhofar by applying the fencing system.
- Forest development programs in Oman and afforestation where it is feasible.
- Comprehensive agricultural development in the Najd, which is the greening of an arid area.
- Falaj restoration and maintenance.
- Development of groundwater monitoring networks. To assess recharge and abstraction (draw down)
- Assessment of brine water resources.
- Developing the monitoring of the brackish water overlap.
- Controlling the leaky wells in Najd of Dhofar.
- Establishing aquifer recharges.
- Protecting agricultural lands from floods.

It is worth mentioning that all the above programs have been carried out by the Ministry's departments without any additional outside help, considering that it contacted a number of international organizations, such as (ICARDA) and (ACSAD) in order to implement joint projects, but the lack of finance prevented the implementation of desertification projects.

8.2 Financial Allocation

Most of the financial resources come from the Government, and the policies and mechanism to combat desertification, was approved by the five-year development plan (1996–2000), regarding to:

(a) **Water resources**

- To continue evaluation and exploration programs of water resources and to compute the wells as well as developing plans and investing the detected aquifer.
- To continue the policies of boosting the underground reserves by building recharge dams and water installations while giving priority to areas of water lack.
- Supporting the efforts exerted to control overgrazing in the Jabal area of Dhofar Governorate to benefit from the vegetation cover in recharging the underground reserves to support the water position at Salalah Plain.
- Taking fast actions towards the use of brackish water in the desert areas for agriculture purposes.
- Expanding monitoring programs of ground water quality and taking the proper legislative and implementing measures to minimize ground water pollution.

(b) **Desert combating projects approved by the fourth and fifth five-year plans are**:

- Limiting and controlling grazing in Dhofar.
- Programs of developing and improving forests in the Sultanate.
- Management of Range-lands in Dhofar.
- Integrated agricultural development at al-Najd.
- Maintenance of Aflaj in Muscat.
- Developing modern irrigation systems in Dhofar.
- Digging wells at al-Jabal and al-Najd.
- Developing a monitoring system of ground water at Al-Batinah and Dhahirah Region.
- Estimating saline water resources at al-Batinah, and Dhahirah Region.
- Developing a ground water monitoring system for Sharqiyah Region.
- Estimating saline ground water at Sharqiyah Region.
- Developing a monitoring system of saline water intrusion at Sharqiyah.
- Controlling wells leakage at al–Najd area, Dhofar Governorate.
- Estimating water resources in Dhofar Governorate.
- Maintenance of monitoring system in Dhofar Governorate.
- Establishing a recharge dams at Rustaq, Barka and Khaboura.

The sixth five-year plan (2001–2005), continued the same policy of combating desertification through the investment in agriculture, water resources and environment.

8.3 Long Term Strategy for Combating Desertification in Oman up to Year 2020

The National goals during the last three decades have been reviewed through the targets in the five-year development plans, have been formulated on the basis of principles and philosophy from the long-term development strategy which commissioned by the Ministry of National Economy (MNE), since the principal directive in the United Nation Plan of Action, (recommendation 22), and UNCCD convention Article (2) paragraph (2) which stipulates that "Achieving this objective will involve long-term integrated strategies that focus simultaneously, in affected areas on improved productivity of Land, and rehabilitation, conservation and sustainable management of land and water resources, leading to improved living conditions, in particular at the community level." With the above quotation, the Combating Desertification in the Sultanate, the following targets/objectives are set for the year 2020:-

(a) Raising the percentage of self sufficiency in food production and improving the status of food security.
(b) Combating Desertification Programs, and projects should be in conformity with National goals, and contributing towards their success, improvement and the quality of life of the inhabitants of lands affected by Desertification and protection of the environment.
(c) Ensure, in accordance with the need and potential of country natural resources, the sustainable development of the two critical factors – water and land; through inter alia, sound integrated water resources management and land reclamation projects.
(d) Ensure public participation in design and implementation of the national action programs (NAPs) side by side with developing and improving public awareness of the desertification problems.
(e) Achieve development of indigenous national, sub-regional and regional scientific research and technology capabilities.
(f) Establishing National Institutional and Technical Facilities for Assessment and Monitoring of Desertification.
(g) Contribute to strengthening of sub-regional and international programs and international co-operation in the campaign, and awareness against Desertification.

8.4 Public Participation

Combating Desertification and reclamation of desertified lands cannot succeed without direct involvement and support of the public, and local communities, thus people in Oman, whether in the north eastern part of the country or the Dhofar Mountains region have long experience and tradition with one form or another type of agriculture for thousands of years. The falaj watering system in the North and

East, and the unique land use/animal husbandry balanced systems of the Jabalis (Mountain dwellers) are two well known examples.

The local participation should build on the positive aspects of people's experience spirit of cooperation and accumulated wisdom, which can be characterized as "Traditional knowledge" in managing their ecosystems. Involved in the NAPs will be further of public awareness and perfection of the public perception of the Desertification problems and methods of its control.

8.5 Implications Land and Soil Management

Fortunately, the preparation of the NCS has coincided with the publishing of results of the Soil Reconnaissance Survey carried out by the Ministry of Agriculture and Fish Resources (MAFR) is collaboration with FAO in 1991 and it shows that, from the total area of the Sultanate of 31.4 million hectares, about 2.22 million hectares are suitable for irrigated crop production, out of which only 790,000 ha are highly to moderately suitable soils (35 %) and 1.43 million hectares marginally suitable, which require varying degrees ad types of reclamation (65 %). The present net reclaimed area (arable) under irrigation is about 125,000 ha, out of which 75,000 ha are presently cultivated with different crops. In the light of irrigation water estimates, it seems that the maximum potential cropped land may not exceed 100,000 ha in the year 2000 and 175,000 ha in 2010 and beyond. Assuming the anticipated development in productivity of land and crops and the increase in productivity and efficiency of irrigation water use, the potentially arable area may reach 250,000 ha in 2010 and beyond. As all these arable lands can be theoretically provided from the highly-to-moderately fertile category, and because of the geographic unconformity between these land categories and the distribution of suitable irrigation water (of salinity less than 5,000 units). The situation might require reclamation of marginally suitable soils or supplying suitable water from areas of abundance to the suitable lands.

9 Proposed Solutions and Means of Controlling Desertification and Halting of Desert Encroachment

The following review the main symptoms and causes of desertification and desert encroachment in the Sultanate and indicates the regions and areas where the problem exists. The proposed policies and measures for containing the problem are summarized here according to the specific causal factors in each area:

(a) **In Dhofar Mountains**:

- to translocate commercial fodder farms from Salalah plain to the al Najd area by granting adequate incentives.

– to motivate big pastoral producers to shift to the al Najd and practice mixed farming after demonstrating its success through a pilot project.
– To reintroduce the autumn rotation in the Jarbeen area at the foot of Dhofar mountains and to persuade and motivate herdsmen to adapt to rotational grazing to stimulate regrowth of valuable forage species.
– to link subsidies to herdsmen and farmers with their acceptance and implementation of the proposed reforms.
– to impose strict penalties on tree logging, and the introduction of import subsides aimed at reducing the prices of building timber as a substitute.

(b) **The Wahiba Sands and the South Western parts of Sharqiyah Region**:

– to motivate farmers to grow shelter-belts for the halting of desert encroachment.
– to rationalize urban planning.
– to start developing the newly discovered water sources in the area.
– to encourage mixed farming in order to minimize the impacts of overgrazing.
– to introduce the system of pastoral rotational gazing.

(c) **In Jabal Al-Akhdhar**:

– to introduce watershed management measures.
– to prepare adequate land use plans before starting the implementation of the proposed development plans for the area, and before the building of new infrastructure, particularly roads.
– to conserve and protect the already scarce water resources; and;
– to introduce ecological farming especially shelter-belts and to improve on contour farming practiced in the Jabal.

(d) **In the Desert and Semi-Desert areas of the Central Plains**:

– to study the dynamics of wind blown sands into the region;
– to utilize brackish water in growing economic trees and developing pastures and to regard this as a long-term investment; and;
– to rationalize grazing and water resource distribution (Fig. 19.3).

10 Conclusion

Oman has realized the importance of the conservation of the environment, the Natural resources and their optimum utilization of the benefit of the present and future generations in sustainable manner through the following:

- Enacting environmental legislation.
- Provision of the administrative and technical bodies to ensure enforcement of the laws.
- Train, develop and qualify the technical staff required to care with these aspects.

Fig. 19.3 Low cost materials (palm fronds and other debris) have been used to stabilize sandy areas and reduce the impact of dust and sand storms

Special consideration was given in the Sultanate of Oman to the problem of desert encroachment in general, and the degradation of some of its agricultural lands in particular. The Sultanate has given special care to the desert encroachment issue due to its geographical location which is connected with the desert within its strategic vision to protect the environment in general and to conserve its natural resources in particular. His Majesty Sultan Qaboos bin Said's vision laid its foundation. He believes that sustainable development in all socio-economic fields cannot be achieved unless under suitable environmental conditions which provide the required balance between securing decent life and stability to citizens and preserving the country's natural resources in a sustainable manner.

On the basis of an integrated national plan for combating desertification prepared in collaboration with ESCWA, FAO, UNDP and UNEP, the Sultanate during the last three decades has undertaken a number of programs and projects aiming at the protection of the productive land, development of rangelands and deserts, specifying land use and studying the relation between arable land and areas of vegetation area and establishment of shelter-belts for the halting of desert creep and development of local life of human settlements adjacent to the desert areas. The Sultanate, by hosting the international working group meeting on combating desertification, indeed is assuring its permanent endeavors towards activating its national programs and plans in this field, enhancing joint work and cooperation between the Sultanate concerned authorities and other Arab and international organizations, particularly parties to the UNCCD which the Sultanate acceded to by virtue of the Royal Decree No. (5) of 1996.

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Part VI
Desertification Control: Problems and Prospects

Here there is a discussion of the differences between controlling the desert (a major pre-occupation of some countries in both Asia and the Middle East) and combating desertification. These two approaches are predicated on entirely different concepts and the measures taken to achieve each of them are quite different.

We conclude the book with some speculation about how the proven practices outlined throughout this book can be replicated and scaled up.

Chapter 20
Desert Development: How Does It Relate to Anti Desertification Measures?

Victor R. Squires

Synopsis An examination of the relationship between desert control and desertification with an explanation of the confusion that has arisen from the similarity of the words.

Key Points

- Partly the desire to tame the desert is fuelled by the notion that 'man is dominant over nature' but interest in the subject is driven by the growing pressure of human population, the diminishing resource base and the widespread poverty that is a feature of many desert regions. Even in desert areas where there is no permanent habitation, protection of the infrastructure, pipelines, electricity transmission lines, railways, and highways dictate that measures need be taken to tame the desert.
- It is now widely accepted that desertification is not the relentless advance of desert but rather the development of land degradation in discrete sites, that can coalesce and spread but the threat of desert encroachment is real on the desert margins.
- The driving forces for the different environmental problems in Asia (as well as in the rest of the world) are fundamentally related to human population growth which increases the use of natural resources and production of wastes. Rapid population growth has contributed to the destruction of natural habits, widespread land conversion, and increased intensities of land use, further resulting in a series of problems of ecosystem degradation including desertification, salinization and alkalization, water-logging, and air and water pollution.

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- The confusion between controlling the desert (a not unreasonable aim) and desertification control has hindered land rehabilitation efforts. A consequence of misunderstanding about desertification, fuelled by the belief that desert spreading is the primary problem, is the planting of sand dunes. Planting, though costly, is technically and logistically a simple operation now perfected by years of investigation in Northwest China and in Iran (and elsewhere). The benefit/cost ratio of planting is low or negative. But planting is visible and gives the impression that something is being done. It allows government agencies to avoid tackling the much harder social and economic problems of insidious land degradation.
- Phenomena like desertification involve environmental, economic and social factors. The combined effects have either been ignored or treated in a one-sided manner. Progress in combating desertification will require a major re-think and the application of holistic approaches such as Integrated Ecosystem Management.

Keywords Integrated Ecosystem Management • Desert encroachment • Desert margins • Land conversion • Population pressure • Holistic • Cost/benefit ratio • Dryland development • Water scarcity • Infrastructure • Transport routes • Irrigation

1 Introduction

Desert development involving desert transformation is a recurring theme as evidenced by the number of international conferences on the subject (Box 20.1). Eleven International conferences have so far been organized by the International Commission on Dryland Development (ICDD) and the twelvth is planned (Box 20.1).

Partly the desire to tame the desert is fuelled by the notion that 'man is dominant over nature' but interest in the subject is driven by the growing pressure of human population, the diminishing resource base and the widespread poverty that is a feature of many desert regions. Even in desert areas where there is no permanent habitation, protection of the infrastructure, pipelines, electricity transmission lines, railways, and highways dictate that measures need be taken to tame the desert.

A clear distinction should be made between those interventions (Chaps. 2 and 3) designed to control desert encroachment (mainly tree planting, creation of shelterbelts and erection of mechanical barriers) and land management practices (designed to control dust storms, restore degraded rangelands, and arrest and reverse soil erosion). Over emphasis on the former and neglect of the latter is commonly observed throughout China's drylands (Yang Youlin et al. 2002) and in some North African and Middle Eastern countries (Omar et al. 1998; El-Beltagy et al. 2006).

It is now widely accepted that desertification is not the relentless advance of desert but rather the development of land degradation in discrete sites, that can coalesce and spread (Squires and Sidahmed 1998) but the threat of desert encroachment is real on the desert margins as illustrated by the map of China where the northern fringe of the Taklimakan desert in Xinjiang and the western fringe of the Badain Jaran desert in Inner Mongolia are desertification ‘hot spots’. The problem also exists on the northern and southern fringes of the Sahara desert and in other regions of the world (Fig. 20.1).

Box 20.1: Desert Development Has Been a Strongly Supported Activity as Evidenced by the Number of International Conferences

First International Conference on Desert Development: Application of Science and Technology for Desert Development, Cairo, Egypt, 1978.

Second International Conference on Desert Development: Desert Development Systems – technologies for Desert Agriculture, Energy and Communities, Cairo, Egypt, 1987.

Third International Conference on Desert Development, Beijing, China 1990.

Fourth International Conference on Desert Development: Sustainable Development for our Common Future, Mexico City, Mexico, 1993.

Fifth International Conference on Desert Development: Desert Development- The Endless Frontier, Lubbock, Texas, 1996.

Sixth International Dryland Development Conference: Desert Development-Challenges in the New Millennium, Cairo, Egypt, 1999.

Seventh International Dryland Development Conference: Sustainable Development and Management of Drylands in the twenty-first century, Tehran, Iran, 2003.

Eighth International Dryland Development Conference: Human and Nature working together for Sustainable Development of Drylands, Beijing, China, 2006.

Ninth International Conference on Dryland Development: Sustainable Development in Drylands-meeting the Challenges of Global Climate Change, Alexandria, Egypt, 2008.

Tenth International Conference on Development of Drylands (ICDD): Meeting the Challenge of Sustainable Development in Drylands under Changing Climate – Moving from Global to Local, 12–15 December 2010, Cairo, Egypt.

Eleventh International Conference on Development of Drylands (ICDD): Beijing China, March 2013.

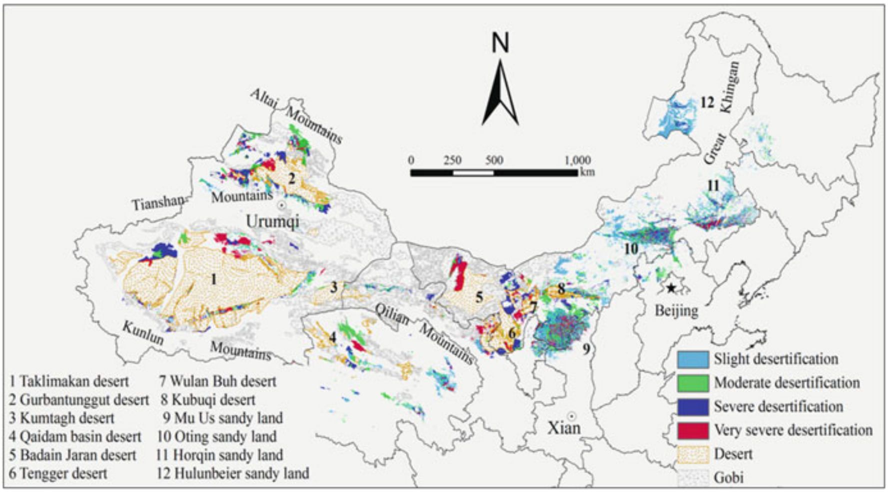

Fig. 20.1 The distribution of true desert and the areas affected by desertification in North China. Note the location of desertification hot spots on some desert margins where sand encroachment is a major concern (Mao et al. 2010)

2 A Chinese Case Study

China is widely recognized as the country with the most extensive and severe desertification, exacerbated by the heavy impact of the world's largest human population (Luo and Zhang 2006). Population density in many of China's arid regions exceed the UN guideline by a large margin. Other countries in the world's drylands have quite high densities as shown by the UN map Fig. 20.2. The pressure exerted for water, food crops, forage and fuel wood are leading to the denudation of entire landscapes.

The driving forces for the different environmental problems in Asia (as well as in the rest of the world) are fundamentally related to human population growth which increases the use of natural resources and production of wastes. Rapid population growth in Asia has contributed to the destruction of natural habits, wide-spread land conversion, and increased intensities of land use, further resulting in a series of problems of ecosystem degradation including desertification, salinization and alkalization, water-logging, and air and water pollution.

The land use pattern throughout NW China seems to dictate the responsibilities of the various line Ministries and their counterpart Bureaus at Provincial, Prefecture and County level. By this I mean that cropland (including the highly vulnerable dry farming regions) is the responsibility of the Agriculture portfolio. Rangelands, especially shrublands are the responsibility of the Forestry Administration. As rangeland is converted (so called land reclamation) from rangelands to cropland it passes to the control of Agriculture. The residual land (sometimes called wasteland) is the responsibility of Forestry whose mandate is to control sand encroachment,

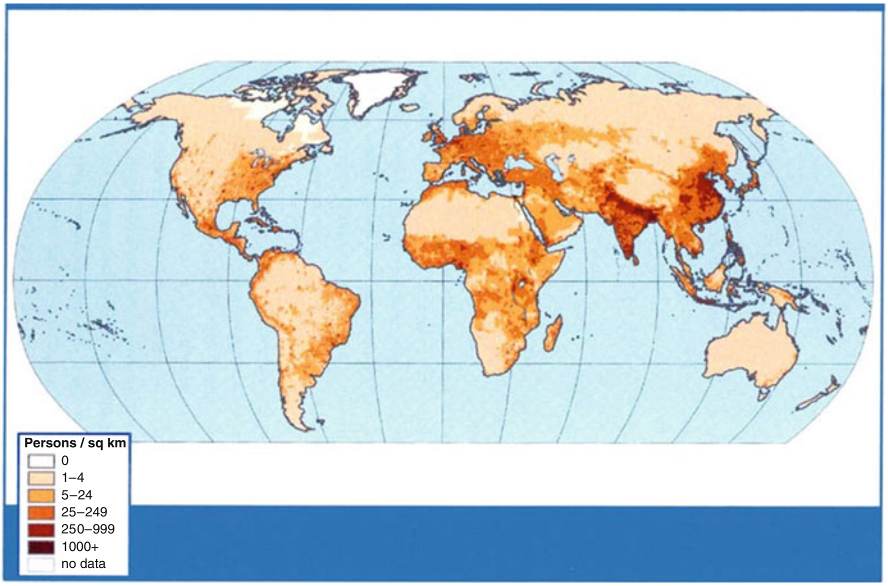

Fig. 20.2 Projected global population density in 2015

prevent desertification and protect the artificial oasis (see below) and the associated urban settlements. Apart from extending the water distribution to sites for tree planting little else seems to be done by Forestry bureaus to control desertification in the rangelands (a major source of dust in dust storms that are a scourge in spring) and whose presence regularly plagues the east coast cities such as Beijing and Tianjin (Yang Youlin et al. 2002). Measures designed to prevent sand encroachment are quite ineffective against dust storms. The finer particle size that characterize the sediment in dust storms derives from the rangelands and croplands where it is lifted and transported at a height far in excess of that of any tree barrier. Sand on the other hand, is rarely lifted above 0.5 m above the ground and is transported by a quite different mechanism (Squires 2002). Trees and shrubs that are planted in strategic locations in belts and blocks can be effective barriers to sand movement (Chap. 3).

A feature of much of the tree planting effort so evident in China today is that follow-up is poor or completely neglected. The enthusiasm of people to volunteer to dig the holes and plant the trees is high. The maintenance of the plantings is neglected and many trees die because of lack of water (Fig. 20.3).

Tree spacing is too close in many instances and the sustainability of such plantings must be seriously questioned. The research institutes within the Forestry sector seem to be providing answers to questions that no one is asking. Practical applied research (problem oriented) is absent or weakly expressed (Lu et al. 2006). One of the research institutes with the longest history in desert control is the Gansu Desert Control Research Institute in Wu Wei in the Hexi Corridor. It was established

Fig. 20.3 Trees can help to prevent sand encroachment but trees require regular watering which is costly and impractical. Plant spacing should not be too close

in 1950 and its mandate was to control the desert. Similar directives were given to the Shapotou Research station in Ningxia (Chap. 3).

2.1 *Taming the Desert*

China's long history of effort to "tame the desert" has clouded the view about land degradation. The root causes of an environmental problem such as desertification are often located in a non-environmental sector, like food-crop production or industry. It is useful to distinguish between "drivers of change" and the subsequent actions in response. There seem to be three major drivers of change that operated in China since the foundation of New China in 1949:

1. The perceived threat to China's national security because of low population density in the strategically important north and western border regions. Massive relocations schemes have uprooted millions from their homes along the densely populated southern and eastern seaboards of the country, resettling them on the remote northern and western frontiers. In Xinjiang in the far north west, Heilongjiang on the northern border with Russia, and Inner Mongolia in the north-east, hardy settlers have converted desert, grassland and harsh shrub into croplands through massive land conversion schemes and development of artificial oases fed by harnessed snow melt from the system of internal rivers.

2. Revolutionary zeal that translated into an urge to colonize the sparsely-inhabited "wastelands" and develop new sites for food production to meet the post-war demands. In the New China, the fight to tame nature has featured as a constant theme born of socialist philosophy.
3. Economic imperatives and the need for more food to cope with the rapidly growing human populations were key factors.

These three drivers were translated into policy initiatives that led to the present day environmental crisis.

2.2 Historical Perspectives on Land Use Change

China's recent, and not so recent, history (Squires and Zhang 2010) holds the key to the present day situation.

In some regions of China's arid zone the seeds for land degradation were sown well before the birth of New China in 1949. In the eighteenth century the areas of China that are now most affected by desertification were populated, for the most part, by nomadic people of the ethnic minorities whose main use of land base was as herders grazing their livestock on relatively abundant rangelands. Farming activities commenced in the late nineteenth century in many regions with an influx of Han nationals in search of unoccupied land for settlement purposes.

Settling of many regions was encouraged by government as a national defense strategy and quickly resulted in only marginal lands remaining unfarmed. In some areas it was clear by mid 1920s that no more suitable land was available for conversion to farmland, yet local peasants were conscripted to meet the food requirements of the military. In fact then, as today, much of the land being farmed was unsuited to that activity. Widespread losses of livestock in the inevitable droughts led to further reliance on cropping and conversion of farmland became excessive (Wang et al. 2006). Figure 20.4 shows the pattern of land conversion and subsequent degradation as human and livestock populations rose.

In many areas of north and west China there has been a progressive program of supplanting the traditional land use (Fig. 20.5), as practiced by the ethnic minorities, with the system of farming developed by the Han nationals. The latter relies on two elements: irrigated cropping and non-ruminant livestock (mainly pigs). It also depends on external inputs (water, fertilizer, energy, pesticides). In those areas where the tradition relied on a nomadic or semi-nomadic existence and where key refugia were reserved for the bad times (droughts/severe winters etc.) a new system was superimposed. Rivers were dammed, water diverted to support new oasis development. Ground waters were exploited to supply irrigated agriculture and settlement. Even the margins of major deserts like the Taklamakan, the Gobi and the Junggar basin were transformed into large scale state farms where irrigation was the means by which crops were produced in these harsh environments (Jia et al. 2000).

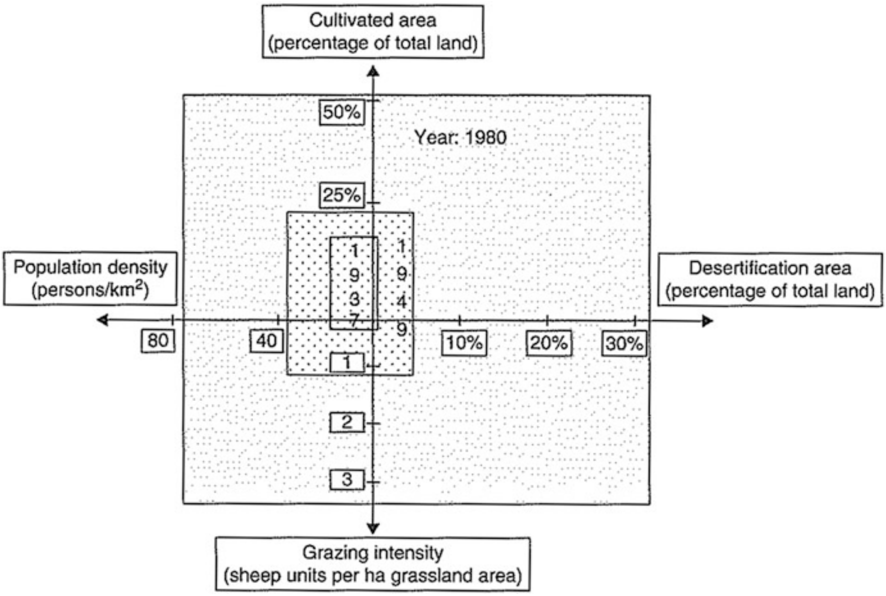

Fig. 20.4 Dynamics between people, livestock, cropland and desertification

The Han system of agriculture had been developed in the more reliable climatic zones of east and central China and was originally confined to the more humid regions of China. They were not always suitable for extrapolation to the arid zone, despite the availability of hitherto untapped sources of snow melt water from the mountains of west China. Soils there were high in exchangeable sodium and had high pH. Irrigation and drainage had to be quite sophisticated. Often they were not.

Salinization often led to abandonment of vast areas because irrigation/drainage techniques were poor and water was frequently wasted (Zhu Zhenda and Lui Shu 1983). Often too, the installation of reservoirs led to reduced downstream flows of rivers and to the creation of even drier conditions under which recruitment of trees and shrubs to the desert environment was no longer guaranteed. Coupled with this the harvesting of fuelwood by the new settlers soon destabilized the desert areas.

By the 1960s the westerly expansion of this system of agriculture that relied on developing the artificial oases was well established. The system was pushed westward and northward but by the 1980s major land degradation problems began to emerge.

From 1949 successive episodes of "land conversion/reclamation" occurred: the first in the 1950s and again in the early 1970s. As increasingly marginal lands were brought into production, crop yields dropped and croplands were routinely abandoned after two rotations. The ill-fated efforts during the Cultural Revolution were particularly damaging. The inevitable consequence of the above land use pattern included the loss of stabilizing vegetation cover, soil structure and moisture

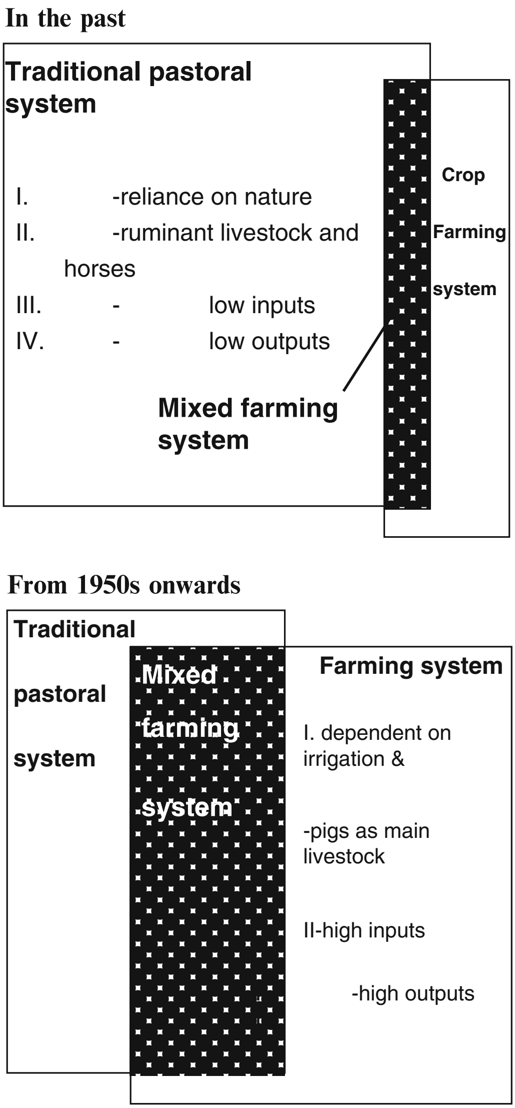

Fig. 20.5 A schematic diagram representing the change in land use systems in the arid regions of northwest China. Mixed farming in this context refers to areas in which the Han system of oasis development co-exists with a less intensive agro-pastoral system

retention capacity – all of which led to severe land degradation and, in the semi-arid conditions, to desertification.

In many areas of north and west China there has been a progressive program of supplanting the traditional land use as practiced by the ethnic pastoralist minorities, with the system of farming developed in more humid regions (Fig. 20.5). The latter relies on two elements: irrigated cropping and non-ruminant livestock (mainly pigs). It also depends on external inputs (water, fertilizer, energy, pesticides)

In the post-revolutionary race for development vast swathes of forest were felled for lumber and large areas of dryland were plowed (even though there was

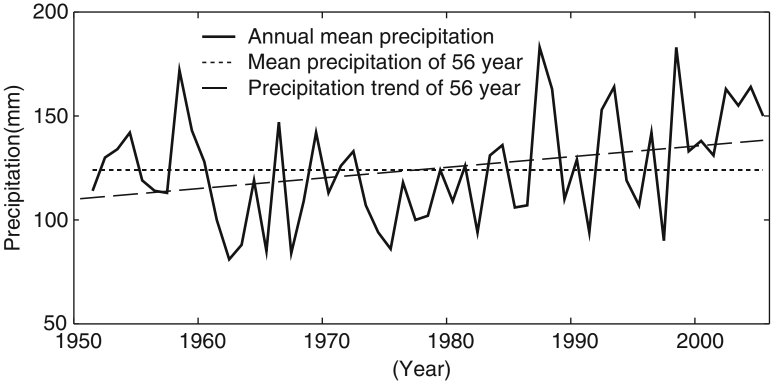

Fig. 20.6 Precipitation in Xinjiang, NW China in the 50+ years ending 2005

insufficient water to irrigate it), then just left to the elements and local peasants and new immigrants, for whom environmental protection was an alien concept.

The recurrent pattern of land use, driven by demands to produce more food, has consisted of converting (so-called land reclamation) untilled land for crop production, low levels of input inadequate to sustain acceptable production levels, abandonment of depleted crop lands after as little as two years, degradation of abandoned crop lands and search for and conversion of other marginally productive untilled lands elsewhere. Persistent and extensive poverty consistently and significantly reinforced this pattern by ensuring that access to much needed irrigation and cropping technology, improved seed and to fertilizer was unaffordable. Efforts to change land use policy and to rehabilitate degraded lands commenced most seriously with land tenure reform about 20 years ago.

Climatic factors obviously played their part (Fig. 20.5). An analysis of the rainfall pattern in representative sites within the four categories of dryland (Lu and Wu 2008) shows that there was a period of below-average rainfall for a period of about 20 years that more or less coincided with the efforts by government to undertake massive land conversion. Ironically, the next 20 years were generally above average (see Figs. 20.4, 20.6 and 20.8).

Experience elsewhere in the world suggests that most dryland systems have considerable resilience but that the sequence of rainfall events is as important as the total amount of precipitation received. For example, a sequence of several years of rainfall near the long-term average followed by one or two years well below average will be more devastating to rangeland than a situation where good (above average) seasons precede drought.

The attempted conversion of large swathes of land, and its subsequent abandonment, near the beginning of a long run of drier than average seasons must have aggravated an already serious ecological situation. Normally in arid land systems the major perennial plant species are long-lived and recruitment to the

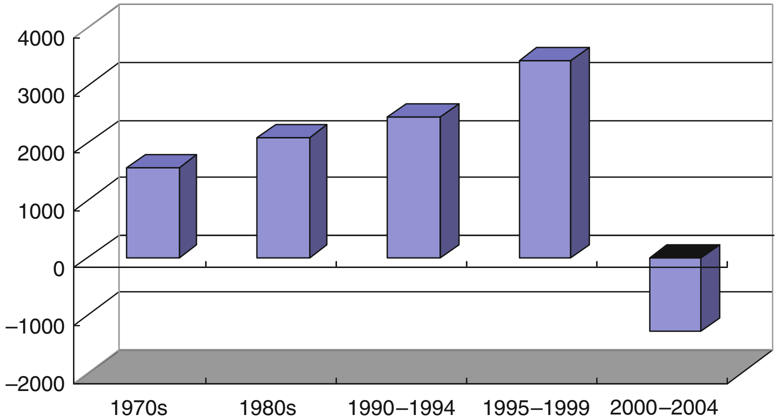

Fig. 20.7 Annual rate of spread of sandification in China. In recent years the areas treated by the methods outlined in Chaps. 2 and 3 of this book have exceeded the areas succumbing to sandification

plant population occurs infrequently. Recruitment (germination and successful establishment) follows the rare co-occurrence of favorable climatic events. This is why it is common to find even-aged stands of trees and shrubs in arid zone systems. If a perturbation, such as land clearing is followed by heavy and sustained grazing, then no recruitment will take place and as the old plants die there is no replacement.

In many of China's counties in Ningxia, Inner Mongolia and Gansu the local officials report that the rate of expansion of desertified lands is proceeding at double the rate of control measures. Clearly, this is unsatisfactory and better ways must be found to reverse the trend. National efforts to combat desertification employ a range of measures, some physical and others relate to socio-economic and policy change (Lu et al. 2005).

Sandy desertification[1] (sandification) is of great concern (Wang Tao 2000). Until recently the area of sandification was growing at a rapid rate, despite efforts to combat it (Fig. 20.5). It is estimated that the rate of rangeland degradation in semi arid and dry sub-humid areas is 90–97 %, and the annual rate of rangeland degradation is accelerating but from 2004 onwards the rate of expansion of land affected by sandification has declined and in some areas it has been reversed (Luo and Zhang 2006) (Fig. 20.7).

[1]Sandification refers to sandy desertification. It is experienced in many areas of China from the sub-humid Hulunbir grasslands in NE China to the edges of the various deserts in western and northern China.

3 Desert Control – A Distraction?

The Chinese preoccupation with "taming the desert" and the constant attempts to create a new oasis, to transform the desert into a better environment is a major distraction from the urgent task of controlling land degradation. Lack of capital investment is stated by many officials as the principal reason for the lack of progress in controlling desertification. When asked about how they might proceed if money was available the invariable answer was to extend the system of irrigation distribution channels and plant trees in the desert i.e. to create a new oasis. There is a complete lack of interest in more ecologically sound and sustainable approaches that rely on native vegetation already adapted to the harsh desert environment.

The confusion between controlling the desert (a not unreasonable aim) and desertification control has hindered China's efforts. A consequence of misunderstanding about desertification, fuelled by the belief that desert spreading is the primary problem, is the planting of sand dunes. Planting, though costly, is technically and logistically a simple operation now perfected by years of investigation in Northwest China. The benefit/cost ratio of planting is low or negative. But planting is visible and gives the impression that something is being done. It allows government agencies to avoid tackling the much harder social and economic problems of insidious land degradation. Phenomena like desertification involve environmental, economic and social factors. The combined effects have either been ignored or treated in a one-sided manner. Progress in combating desertification will require a major re-think (Carrad et al. 2006) and the application of holistic approaches such as Integrated Ecosystem Management (IEM).

In my view unless this contradiction between the aim of desertification control and the Chinese agenda of using foreign loans and grants to transform the desert is resolved little progress can be made in dealing with China's burgeoning problems of dust storms and rural poverty.

There is a reluctance to acknowledge that much of the current land degradation is due to poor land use decisions and flawed development strategies over a long period of time, rather than climate changes or other natural factors. In PRC, the arable land per capita is 0.11 ha. The shrinking arable land area and increasing demand for agricultural products pressures farmers to extract higher yields from their land, at the expense of stable soil structure and adequate organic matter content, leading to increased soil erosion. There is a clear connection between land degradation and poverty. Almost 90 % of rural people living in poverty are located in areas suffering from land degradation. In the dryland areas, rapidly increasing livestock numbers exacerbate the spread of desertification and directly contribute to the increasing frequency and severity of dust storms.

Over 90 % of the rangeland (grasslands and shrublands) in Xinjiang, Inner Mongolia and Qinghai suffer from moderate to severe degradation at a time when livestock numbers are increasing to meet the demand for meat and other livestock products is rising (Fig. 20.8).

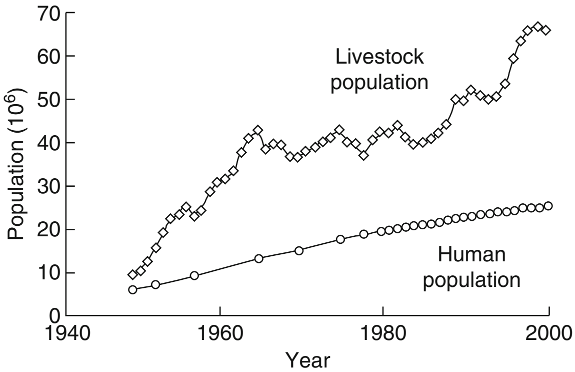

Fig. 20.8 Changes in the growth of human and livestock populations in Inner Mongolia from 1949 to 2000

Urbanization and rising standards of living throughout PRC are the drivers for this. These pressures to produce more are likely to put the rangelands under greater stress and contribute to more frequent and severe dust storms. Efforts to relieve the grazing pressure on rangelands include an expansion of water-demanding artificial pastures and the building of indoor feeding sheds. The long term implications of this system of meat production has not been considered.

In a water-scarce region of the Three Norths (North, North East and North West) it would seem to be more relevant to use the scarce water for domestic consumption or for production of high value crops. A reform of the water pricing policy to reflect the real cost (and value) of water would soon force the rational use of water. Water allocated for tree planting to protect the oasis, the urban areas, industrial sites and important infrastructure like roads, railways and power transmission lines, canals, reservoirs etc. should be priced differently, depending on its use. For example, it could be worth 100 times more to protect valuable infrastructure than it is to protect cropland on the edge of the oasis. This implies that the "user pays principle" should be adopted. Higher water use charges can be easily met by urban communities, industry and the authorities who build and maintain infrastructure such as railways and roads etc. Water used to beautify the urban environment and to "green" the environment might attract a different scale of charge. Priority in the use of scarce water should be assigned on the basis of need and the willingness to pay.

4 Agricultural Development of Arid Territories

Agricultural development causes change in geographical, ecological and social conditions of arid land. Often the results of agricultural use of arid lands are desertification processes that negatively impacts flora and fauna of deserts. At the

Fig. 20.9 Farming on the desert fringe in western Gansu Province, China

Fig. 20.10 Saline and sodic soils need especially adapted plants

same time irrigation gives rise to soil degradation. As a result large regions can acquire new characteristics. Agricultural development can stimulate movement of animals and plants and also the regrouping of species in communities, both as temporary and permanent phenomena. The region can be completely transformed both ecologically and economically (Squires 1989) (Fig. 20.9).

The same plant associations can be found in introduced cultures almost anywhere in the world. Irrigation can also lead to important spatial regroupings of animals, both through making the irrigated area wetter and making the donor area dryer. Certain rules can be considered as a basis for eco-geographical forecasting of change in ecosystems as a result of widespread development of arid territories (Fig. 20.10).

5 How Can We Prevent or Reverse Desertification and Land Degradation (DLDD)?

Prevention is an important consideration but outside of the scope of this book. Effective prevention of desertification requires both local management and macro-policy approaches that promote sustainability of ecosystem services. It is advisable to focus on prevention, because attempts to rehabilitate degraded areas are costly and tend to deliver limited results. Measures designed to reverse DLDD are outlined for a variety of situations from the deserts of China, Africa and the Middle East to the high rainfall regions in Asia. Some aspects of this question will be also be dealt with in Chap. 21.

There are two important questions

Why are actions needed? Desertification and land degradation (DLDD) lead to loss of productivity impacting livelihoods and economic viability leading in the worst situations to worsening poverty. Ecological stability is another consequence that affects sustainability in the long term.

What actions can be taken to prevent desertification and land degradation? Because DLDD is an on-going process some actions may be more urgent than others and temporary or stop gap measures may need to be employed. However, since DLDD processes involve many issues – bio-physical, socio-economic and cultural and spiritual aspects (Zhang et al. 2007) and necessarily need political, legislative, institutional, and policy reforms. Once these are in place, administrative follow up and enforcement of regulations is required. In short, creation of an enabling environment is a first step. (Squires 2012, see also Chap. 21).

The principal benefits to society from arresting and reversing land degradation will be higher household incomes, increased productivity of farming systems, conservation of biodiversity, increased carbon sequestration, and fewer floods and landslides.

More sustainable land use practices can help but sustainable farming systems and practices will be adopted when, and only if, they offer farmers a convincing opportunity to earn higher profits than from any other systems. There really are two clear and fundamental elements of "better land *stewardship*" – *awareness and action*. That means (i) recognizing our collective responsibility to retain the quality and abundance of our natural resources and (ii) putting that awareness into action by making the appropriate decisions for how to best use and manage these resources not only for today but for future generations as well. This has aspects of improved stewardship but needs to be seen against a background necessity for livestock keepers and farmers to provide a livelihood.

Finally, we must remember that current systems often are used because they were used the year before, are proven, reduce short-term risk, and require modest investment and a low level of management skill and equipment.

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Chapter 21
Replication and Scaling Up: Where to from Here?

Victor R. Squires

Synopsis The concepts of "*replication*", and "*scaling-up*" are being increasingly promoted as important elements of efforts to combat desertification and arrest and reverse land degradation by donors, governments, and non-governmental and community organizations. In this chapter the opportunities, problems and prospects for scaling – up and replication are discussed.

Key Points

- The proven practices described in this book include practical, on-the-ground measures as well as legislative and policy initiatives that have been effective. Where success has been observed with a demonstrable development dividend there is a desire to advance that success on a larger scale through scale-up and replication The more common questions posed by the international development community are: how can successful ideas be grown and adapted to other regions, countries and sectors, in order to fast track progress towards development goals, including arresting and reversing land degradation?
- Communicated effectively, success stories can create a demand driven approach whereby communities actively seek opportunities to apply proven technologies and management models in their communities. The examples outlined in this book are from a wide range of environments and social and political systems and should provide encouragement to local communities both within the countries from which the Case Studies are drawn.

Keywords Transformational goals • Training • Enabling environment • Scale • Demand-driven • Top-down • Institutional change • Transferability • Grass-roots • Innovation • Donor • Livelihoods • Strategic partnerships • Lessons learned

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1 Introduction

The concepts of "*replication*", and "*scaling-up*" are being increasingly promoted as important elements of efforts to combat desertification and arrest and reverse land degradation by donors, governments, and non-governmental and community organizations. Interpretation of the meaning of these concepts is often blurred however, by inconsistent application of their use in the literature. The consistent failure to sustain impetus after the demonstration/project/pilot study has ended, has increased interest in understanding how to institutionalize and diffuse effective innovations. The process of large-scale replication often is called diffusion, replication, roll out, going-to scale, or scale-up. The terms can be used interchangeably. Experience in these matters has evolved over many years of implementing demonstrations and working to replicate innovations on a large scale. UN Agencies such as the IFAD, UNEP, UNDP and a number of NGOs have distilled their experience into a number of documents. Lessons learned have been enumerated and guidelines for success have been formulated.

1.1 Scaling-Up and Replication

The terms replication and scale up tend to be used in tandem but the concepts are somewhat different. Replication (sometimes called "scale out") refers to the transfer to a different location of a tested concept, a pilot project, and so forth, in order to repeat success elsewhere. Scale-up usually refers to taking a tested concept, pilot project, initiative, and expanding it, in terms of people served, revenues generated, or other similar targets. The use of the terms "*Replication*", and "*Scaling-up*" are often overlapping and used interchangeably with one another to describe similar activities.

To replicate or scale up a program or a successful proven practice is to significantly increase its impact in size, amount or extent. Scaling an impact can occur in many ways, encouraging widespread adoption of the model by others or creating strategic partnerships that enable greater reach. It may also involve strengthening an organization's own capacity (capacity building).

1.2 Taxonomy of Processes

Gillespie (2004) provides one of the more comprehensive taxonomies of scaling up processes to achieve significant development at the local/community level. Gillespie's ideas are elaborated in Table 21.1. He recognizes four main categories:

- **Quantitative**, where a program expands in size, geographical base, or budget;
- **Functional**, involving increases in the types of activities and integration with other programs;

Table 21.1 Scaling-up processes (After Gillespie 2004)

Quantitative scaling up	
Spread	Increasing numbers of people spontaneously adhere to the organization and its programs, perceiving them to serve their interest/preferences
Replication	A success program (methodology and organizational mode) is repeated elsewhere
Nurture	A well-staffed and well-funded outside agency, using a specific incentive-based methodology, nurtures local initiatives on an increasingly large scale
Integration/mainstreaming	A program is integrated into existing structures and systems) in particular government structures after it has demonstrated its potential
Functional scaling–up	
Horizontal	Unrelated new activities are added to existing programs, or new initiatives are adopted in the same organization
Vertical	Other activities related to the same chain of activities as the original one are added to an existing program (upward or downward linkages are made)
Political scaling-up	
First generation	Essentially service delivery
Second generation	Community capacity development for self-reliant action. Through better information and mobilization, an organization's members of a local community are stimulated to participate in the body politic
Third	Beyond the community influence policy reform to foster an enabling environment. This may involve networking and aggregation of organizations into federative structures designed to influence policy
Fourth	Beyond specific policies, catalyze social movements[a], and/or direct entry of grassroots organization (or their leaders) into politics (either through creating or joining a political party)
Organizational scaling up	
Internal management	Increasing organizational capacity and improved management processes (links to effectiveness and efficiency)
Financial viability	Increasing financial viability/autonomy including self financing through sub-contracting consultancy fees for service
Institutional diversification	Both internally and externally (including diversification of donors) and linkages with other actors/organizations. Institutional diversification

[a]In Australia and elsewhere now (through replication) the LANDCARE movement is an example

- **Political**, involving increases in political power and engagement with wider political processes;
- **Organizational**, involving increases in organizational strength

The underlying assumption in this taxonomy is that there are external drivers, and support, for scaling up development at the local level, with the core recommendation that this development be anchored within existing contextual systems, processes and frameworks. Start-up small, micro and medium sized enterprises that have strong local involvement may recognize that they would benefit from these processes, but it could be well beyond their capacity to initiate and sustain these processes in order to secure their own growth and impact.

1.3 Replication

Replication is not straightforward. Improving the communication of good ideas, even providing seed funding to attract potential entrepreneurs to replicate an idea, will not be enough. Success factors for an initiative will be grounded in the local context, for example:

- the experience and commitment of the individuals involved;
- receptivity among the local beneficiaries;
- a favorable enabling environment (see below).

An exact replication is therefore never possible; but without similar favorable circumstances in place, successful replication cannot be easily assumed. Leadership and ownership of the initiative in other jurisdictions may be problematic, especially if the replication is underwritten by significant donor dollars rather than being fostered from the grass-roots. There may not be sufficient resilience in the new community in the way of technical support, access to micro credit and other factors that could help to mitigate set-backs in implementation. Legal and regulatory frameworks may well be different. All factors contributing to the success of the original demonstration/pilot must be examined in order to assess the feasibility of replication. Even with this effort, the risk of failure may be high.

Efforts to replicate and scale-up often are inadequate because (a) key facets and specific tasks related to each phase of not pursued and (b) appropriate change mechanisms are not established.

Implementing and scaling-up a comprehensive prototype almost always requires *phased-in* change and the addition of *temporary infrastructure mechanisms* to facilitate change. One way to conceive a mechanism for change is in terms of well-trained change agents or organization facilitators. Such staff are needed to disseminate a prototype, negotiate decisions about replication, and dispense the expertise to facilitate implementation and eventual scale-up changes may encompass introducing one or more interventions, developing a demonstration at a specific site, or replicating a prototype on a large-scale. The push for scale-up may have the unintended consequence of endangering a resource or an ecosystem.

1.4 Enabling Environment

Practitioners and independent analysts now advocate that an **enabling environment** must be in place to support scale-up and replication. What constitutes an “enabling environment" will vary, depending on the type of initiative being proposed for expansion. But in general, researchers identify access to financial, technical and political support; supportive policy, legal and regulatory frameworks and better policy coordination and a range of capacities within different levels of government, including documented procedures, detailed planning, good systems for sharing, spreading knowledge, incentives for stakeholders, and building on experience and existing institutions. Small-scale interventions, while they can provide valuable local benefits, may "remain little more than islands of excellence in a wider economic and institutional environment which is detrimental to the poor" (Uvin et al. 2000, p 1409). However, advocating for, or creating this enabling environment is often well beyond the capacity and scope of influence of most rural communities where the land degradation control measures need to be put in place.

What constitutes an "enabling environment" will vary, depending on the type of initiative being proposed for expansion. But in general, researchers identify:

- access to financial, technical and political support
- supportive policy, legal and regulatory frameworks and better policy coordination
- and a range of capacities within different levels of government, including documented procedures, detailed planning, good systems for sharing, spreading knowledge and incentives for stakeholders.

2 Sustainability and Scaling-Up: It's About Systemic Change

2.1 Step Changes and Transformational Goals

Throughout the literature, it is clear that development practitioners and analysts are looking for a significant "step change" in development – achieving measurable poverty reduction at national levels; improved performance on indicators for health and education; preservation of biodiversity and natural resources managed sustainably

Several aspects are important:

- How to create the enabling environments necessary for technology transfer and its replication elsewhere?
- How can successful approaches be adapted to other regions, countries and sectors?
- Who drives the larger scale up and replication agenda?
- Who should take ownership and responsibility for step change towards sustainable development

Scaling-up is really about systemic change that must proceed as a series of step changes that are required to achieve transformational goals, it is clear that development practitioners and analysts are looking for a significant "step change" in development – achieving measurable poverty reduction at national levels; preservation of biodiversity and natural resources managed sustainably.

Experience has led to development of 8 key steps related to the first two phases of the change process (i.e., creating readiness and initial implementation). These are organized into four "stages." The stages are conceived in terms of the need to intervene in ways that (1) develop a strong argument, (2) mobilize interest, consensus, and support among key stakeholders, (3) clarify feasibility, and (4) proceed with specific systemic changes.

Box 21.1: Eight Steps to Scaling Up

The scaling-up process requires a tremendous amount of negotiation, diplomacy, patience, flexibility, time and resources to be successful.

1. Establish that the technical intervention, methodology or approach that is being considered for scaling up leads to desired results through carefully evaluated and documented research.
2. Assess possibilities for scaling up (need, available resources, political will, potential partners, etc.) and potential barriers to scaling up (opponents and their arguments, policies, etc.).
3. Build consensus for scaling up among decision makers, implementers and leaders of those who participate in the program use the intervention through meetings, presentations, field visits, etc. with key individuals and groups.
4. Ensure that policies are supportive and that resources will be available.
5. Develop plans/proposals with decision-makers and implementers on the organizational structure and relationships of the scale-up, activities, management, monitoring and evaluation, training and technical assistance, etc. Program designs or interventions should be simplified as much as possible and should be accessible in "user friendly" language.
6. Be prepared to solicit many donors and negotiate many hours in order to put all pieces into place. The amount of funding needed for large scale programs is often not available through only one donor. Negotiate contracts, budgets, work plans.
7. Prepare training and technical assistance teams and matter to work at regional or other level depending on organizational structure. Be flexible and adapt to meet local conditions whenever possible without losing essential elements of quality.
8. Program implementers meet regularly on local, regional and national levels to monitor progress, detect problems, develop innovative solutions/approaches, strengthen skills and build team. Ensure that representatives from those who are participating in the program (community men and women, etc.) participate in monitoring and evaluation at a minimum at the local level

An overriding concern in pursuing each step is to do so in ways that enhance stakeholders' readiness, especially motivational readiness. A particularly persistent problem in this respect is the fact that stakeholders come and go.

Major systemic changes are not easily accomplished. Awareness of the myriad political and bureaucratic difficulties involved in making major institutional changes, especially with limited financial resources, leads to the caution that the type of approach described is not a straight-forward sequential process. Rather, the work proceeds and changes emerge in overlapping and spiraling ways.

When a broad range of stakeholders are motivated to work together, they come up with more creative and effective strategies than any manual can prescribe. Thus, while concepts and procedures are invaluable motivationally ready and able to proceed is the first and foremost consideration. The necessary motivation comes from the desire to achieve better outcomes; it comes from hope and optimism about a vision for what is possible; it comes from the realization that working together is essential in accomplishing the vision; it comes from the realization that working together effectively requires systemic changes that ensure each partner's assets and contributions are valued.

Because substantive change requires stakeholder readiness, if this is so then, it is a matter of carrying out plans with full appreciation of the complex dynamics that arise whenever complex systems undergo change.

As a part of the strategy for creating synergy and dissemination of technologies there is a need to set up replication funds, which focus on institutional methods of learning. The purpose of such a fund would be an encouragement of successful innovations spearheaded by successful NGOs and CBOs who are already partners by supporting the adaptation of their proven solutions to different contexts. This replication could provide the transferability and scalability of innovative approaches spawned by organizations working at the grassroots. This would not only help in the process of compilation and documentation of 'proven practices' but also support the actual replication of proven interventions by those who have already had pragmatic results through implementation of these social innovations. In order for replication to be successful it is necessary to establish a new model for replication and innovation. Shift from a completely grant based approach to a community based locally owned model, where the local community pays a part of the replication scheme. It is also important to include the NGOs/CBOs and the villages in the particular region to plan and manage the replication schemes. One has to take the opportunity to go beyond grant giving, to seek ways of scaling up, replicate successful experiences, reach out through innovative communications, and promote advocacy strategies to influence policy on key environmental issues.

Policy-makers and donor program managers should revisit their stated intentions to support scale-up and replication with the following points in mind.

1. **Clarify program expectations** for scale up and replication. Consider what, realistically, can be achieved.
2. **Offer tailored support**. It may be more appropriate to focus primarily on helping to improve the chances for success of the enterprise by providing tailored services

such as business and related planning support. Feasibility studies also need to be supported in many cases, together with social and environmental impact assessments.

3. **Assess project context and seek to create an enabling environment**. A key role for programs as promoters of larger scaling up efforts will be the identification and resolution of challenges and barriers that are beyond the scope of influence of the enterprises themselves. Again, this requires a more engaged approach and a thorough assessment of the context in which an innovation is functioning in order to determine what the challenges are and how they might be resolved. This will require greater links to local, national and regional actors.
4. **Longer term**, **proactive engagement**. For greater sustainable development outcomes, programs must take a more proactive, longer term engagement with communities to help them increase the scale and impact to a level which leads to a step change in sustainability in a given country or sector.
5. **Improved monitoring and reporting**. Programs will need to establish credible performance monitoring to assess whether the step changes are in fact being achieved. There is little evidence of specific concerted or established strategies for identifying and reporting on the success of scale-up, or strategies for both promoting and reporting on where the project might have been replicated elsewhere.
6. **For replication**, **foster peer learning**. With respect to replication, incentives will be needed to encourage the originator to transfer their ideas, approaches and lessons learned to others. If they are in agreement to having their idea tested and developed by others, then the key to this effort will be the active fostering of peer learning, by linking replicated practices to the original. Building the community of practice around the initiative being replicated will help to mitigate differences encountered in implementation and might transfer valuable lessons back to the originator as well.

Key elements of success in replication and scaling-up involve working with local and national government counterparts from the design stage of the project to ensure adoption and identifying and creating links with relevant development programs to ensure sustainability.

2.2 Lessons Learned

- Leadership and ownership of the project at the highest level of government are essential for sustainability, replication and scaling up of the initiative at the national level.
- The challenge in attracting and retaining private sector firms to participate in this type of initiative must be addressed.

- Credibility and institutionalization of the certification process are critical.
- Flexibility and adaptability of the training and certification process are essential to ensure both effectiveness and timeliness in the delivery of training and certification.
- Communication and public awareness of the gender equity seal are vital for ownership and recognition in firms and the general public.

Real participation means involving citizens at every stage and level. This includes the micro or community level, the meso or intermediate level (local governments, NGOs) and the macro or national/policy level (central government, donor organization staff). Real participation implies that development choices are taken under conditions of full information, full representation of all interests, and a hard budget constraint. These conditions can be met in substantial measure, if not fully, by good program design. Under these conditions, elites will be driven towards proposals that benefit all stakeholders, including poor and marginalized groups. Some caveats are in order. If poor and marginalized groups are prevented from participating effectively, elite capture will follow. Similarly, if community members dependent on natural resources and other environmental interest groups are inadequately represented, environmental degradation may result.

Empowerment means real control by communities over resources, project/program design and selection, implementation, and M and E. A good test of whether a pilot program will foster empowerment is whether the community/local government have full control over the financial resources to be used in the program, i.e. whether ***the money is in the hands of the community***, and whether these resources are part of a ***single untied development budget***, rather than earmarked for specific purposes.

Shifting power from the top to the bottom requires strong political commitment. Good design is all important: without it, power may simply move from ineffective central governments to ineffective local ones. So, empowerment requires both political commitment and good design. These in turn should be used to ensure six critical factors (Narayan Deepa 2002).

1. Devolution of authority and resources.
2. Real participation of primary stakeholders (see above).
3. A communication program that provides a two-way flow of information.
4. Co-financing by communities to promote local ownership.
5. Availability of technical assistance and facilitation from the private sector and/or higher administrative levels.
6. Pro-poor market development, including facilitation of producer/user groups that can federate upward to tap national and global markets.

Many countries have deep gender and social divisions. Empowerment requires the bridging of social divides and participation by all. A thorough analysis of social/political conditions needs to guide the program design.

3 Key Findings from Field Work in Africa, Asia and the Middle East

It is critical to adapt to the local context. The very fact that successful pilots have not automatically scaled up shows that, whatever their merits, they may require adaptation to succeed in different contexts. What appears to be best practice in one setting may be poor practice in another. While it is useful to draw lessons from successful experiments within a country and from global experience, project design must be adapted to the local context.

- Programs to combat desertification and arrest and reverse land degradation (at any meaningful scale) require the use of host country human resources for training and implementation.
- A cascading training model (e.g., national- or regional-level trainers train local governments and local government-level trainers train communities) is effective for implementation of land rehabilitation projects at scale.
- Trainers must have both technical, subject matter expertise and training skills.
- High-quality, standardized training materials and methodologies—i.e., maximum use of experiential learning cycle, easily translatable language, and inclusion of a facilitator guide, a participant manual, and visual aids—enable quality replication of projects at scale.
- Development of national or regional training resources facilitates replication in other regions, districts, and countries.
- Monitoring training outcomes ensures quality programs.

Two key lessons have emerged. First, training skills are essential at all levels (national, regional, and local) to implement an at-scale land rehabilitation program; and second, a training program must focus at the local government level for implementation.

Six areas that usually need further improvement:

First, the lack of a formalized, strategic approach to training, one that follows established standards, has led to inconsistent quality in training results.

Second, training materials developed during implementation need updates and revisions that include new learning and apply more rigor to methodologies and documentation.

Third, training skills have received less attention than subject matter content. Though trainers need knowledge of the subject matter, they also need the skills to facilitate groups and manage training sessions and timetables etc.

Fourth, initial project successes have led other countries to express interest in replication. This replication requires sharing of materials and expertise, a challenge that often requires localization of training materials—for example, translation into local languages or use of culturally relevant examples—and support visits by qualified trainers. Both of these require resources and so this aspect has not yet been fully developed.

Five, Strengthen the Training of Trainers (TOT). Improving the ability of trainers to train others needs to be prioritized. TOT designs should ensure that trainers attain not only knowledge of training content but also the requisite facilitation skills to train others.

Six, Develop training resources for regional use. Programs in several countries have identified the need to develop regional training resources. As part of this effort, training materials should be translated into local languages if more than one is spoken in the desertified areas and national training resources should be developed and/or reinforced for regional purposes

Leveraging human resources is essential to reach scale in a given country. Local government (e.g., districts) is the key focal point for training. Local government is the appropriate level to focus training efforts for scaling up because the local government structure is country-wide, increasingly responsible for rural development initiatives, and typically has access to a cadre of educated professionals (teachers, administrators, and other professionals) available for implementation. Local governments provide a country-wide human resource base for scaling up. Local government-level trainers use hands-on methods to teach.

National and/or regional training resources must be identified. Qualified training partners are essential to ensure sustainability and quality of program implementation within and between countries. When introducing the project in a new district or region, qualified trainers with experience will improve the quality of replication. As new countries attempt to replicate this program, training expertise in one country can be utilized by consultants in another country there are still questions that need to be addressed:

- Capacity building will play a large role in replication, but who will manage a nationwide capacity building program?

    How can training be institutionalized and made sustainable?
    How can partners best contribute to rolling out and managing a new program?
    And what will be the role of national governments in implementation?
    When national governments develop and/or refine trainers' skills, the trainers become more marketable.
    How can these trainers be retained to carry on the work of scaling up rural sanitation?
    What type of incentive schemes might be used to increase retention?
    Are there opportunities to tie trainers' performances to incentives in other jobs they might have, for example, as teachers?

Training of Trainers (TOT) should ensure that trainers have both relevant technical knowledge and the skills to train others. Content specific knowledge can be ensured through establishing criteria for trainer selection that include field experience. For example, a district-level facilitator should be trained to train others only after they have experience in the field implementing the activities they will train others to do. High-quality training materials must be developed to ensure best results within and between countries. During the replication phase, training materials are an essential element for transferring learning. Materials must be developed by qualified training design experts and must adhere to pre-established training standards to ensure high quality. They must be easy to adapt to different cascading levels – for example, community level materials require more visual aids due to literacy issues, whereas district- or provincial-level materials utilize more text – and must be easily translatable into other languages.

4 Scaling-Up and Replication in Practice

Building the community of practice around the initiative being replicated will help to mitigate differences encountered in implementation; and might transfer valuable lessons back to the originators of the practice as well.

Pursuing the work requires

- strong facilitation related to all mechanisms
- redeploying resources and establishing new ones
- building capacity (especially personnel development and strategies for addressing personnel and other stakeholder mobility)
- establishing standards, evaluation processes, and accountability procedures.

4.1 Difficulties Arising from Co-production May Not Be Mastered

Scaling up implies the co-production of investments, outputs and services by many different stakeholders at many different levels: community workers, local government officials, NGOs, the private sector, technical specialists at all levels, administrators, program managers and bureaucrats, politicians and aid agency personnel. Three problems afflict co-production.

Differences in values and experience of co-producers. Community workers and local NGOs often do not understand how higher levels or sector specialists operate or can contribute. Sector specialists often underestimate latent community capacity. Higher-level administrators are used to strict controls and cannot understand how social capital can enable communities to hold their leaders accountable. Until program participants learn to adhere to a common set of values and approaches, scaling up will remain difficult.

No clear assignment of functions to different co-producers. Scaling up requires precise assignment of a long list of functions to specific actors at different levels, and clear instructions on what they should do, how to do it, and *what tools to use* (forms, questionnaires, technical approaches, training materials, etc.). The problem is compounded in multi-sectoral programs, where all sectors need to harmonize with common basic rules and procedures while using sectoral best practice and norms. A *field tested operational manual is often missing or incomplete* i.e. does not contain sub-manuals and tools critical functions or levels. Operational manuals are too often designed in an office, not the field.

Incompatible incentives of co-producers. Co-producers lacking compatible incentives will either produce low-priority outputs that bring them rewards (such as reports or workshops) or obstruct the program. Public sector workers, such as teachers or extension agents, may not gain from the program. Technical specialists may lack incentives to produce the specific inputs required. Communities may lack incentives to co-finance the program. The central bureaucrat or sector manager may lose budgets and staff by devolving power. Field-tested roll-out logistics in a single district would unearth all these incentives issues, and help design an incentive-compatible operational manual.

4.2 Adaptation to the Local Context May Be Missing

What looks like best practice in some contexts may fail in others. Pilots may succeed because of special circumstances relating to geography or the socio-political context. Scaling up should be adapted each context. Ideally, process monitoring should provide continuous feedback that enables the scaling-up process to constantly be improved.

4.3 Lack of Scaling-Up Logistics

Scaling up can cover tens of thousands of widely-dispersed communities. So logistics must be designed to train hundreds or even thousands of program participants and disburse resources to numerous communities, an issue that does not arise in successful pilots. Scaling-up logistics must control costs, otherwise fleets of jeeps, enormous travel allowances, and expensive training equipment can make national scaling up fiscally impossible. Not enough scaling-up programs design and field-test logistics carefully and cost-effectively.

When programs are approved without resolving these five issues, the newly appointed program managers bear the consequences. They rarely understand fully the need for a detailed design and testing phase. Such programs quickly run into bottlenecks. Typically, the donor sends out a supervision mission to fix that bottleneck, rather than operate at a more strategic level. The program cranks up but quickly runs into more bottlenecks, more missions come to the rescue, and the vicious cycle continues. Fatigue sets in, lack of capacity is blamed for the failure to reach cruising speed, and willingness to pay for scaling up fades away.

To overcome these problems, (Binswanger and Aiyar 2003) recommend that main analytical focus should be on five classes of remedies.

1. Reducing economic and/or fiscal costs
2. Overcoming adverse institutional barriers
3. Overcoming problems associated with co-production by (a) fostering a common culture and vision among program participants; (b) assigning and describing program functions and tasks to different actors and levels; and (c) providing incentives compatible with program objectives
4. Using pilots to test what works in which context, adapting best practice to local conditions, using process monitoring and constant feedback to keep adapting and improving programs.
5. Designing and field-testing the operational manuals, toolkits and scaling-up logistics

Box 21.2: The Many Facets of Success in Scaling Up

Drawing on case studies, an ARD paper by Jim Hancock "Scaling up Issues and Options" identifies a wide range of reasons that facilitate success in scaling up. Some key reasons:

Strong political commitment was vital for success, helping overcome resistance to change and facilitating the transfer of funds and technology to communities.

Strong NGOs and a lively civil society helped greatly.

All successful scale-ups created sophisticated, context-specific procedures, incorporated in manuals with simple transparent messages. These manuals/procedures were, however, living documents that were constantly adapted in the light of new experiences and contexts.

All successful cases had detailed planning from the micro to macro dimension. They benefited from a realistic assessment of financial resources, needs, and institutional realities.

Successful cases had good systems for sharing and spreading knowledge. These helped ensure that different stakeholders knew precisely what their roles were, and helped provide incentives compatible with roles. No-till farming and microcredit spread fast by person-to person and community-to-community contact.

Appropriate incentives for different stakeholders proved important. Managerial incentives were aimed at getting the right outcomes rather than rapid disbursement. Establishing the right processes took time and effort. Once the processes were well established, disbursement picked up.

Some projects succeeded because they built on many years of past experience and utilized institutions already created, in part or full. Best practice from

(continued)

Box 21.2 (continued)
earlier experiences provided a useful starting point, but required adaptation to each context.

Scaling up is a long-haul process needing political commitment and patience over long periods. Flexibility in sequencing needs to accommodate this (Hancock 2003).

5 Conclusions

Scaling up requires a well-designed communications program. Information, education, and communication activities have to meet awareness and learning needs, as also process monitoring needs. Equal access to information by all participants is critical for welfare-enhancing social choice. Decentralization, community empowerment and capacity building can be aided by a multi-dimensional communication program which will also contribute independently to information, voice and organizational capacity.

In conclusion, scaling-up and replication challenges project strategies demanding changes to overcome socio-economic, geographical and policy barriers. Committed individuals significantly increase potential for success and wider institutional base is required for scaling-up and replication. Successful pilot projects undergo a transition phase of survival needing collaborative action. In scaling-up and replication the stage-wise approach is important. Creating local support structures are important and require formal arrangements. Ownership sharing is a vital strategy to facilitate emergence of local leaderships to strengthen the human line up needed for scaling-up and replication process for long term sustainability (Mansuri and Rao 2004).

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Appendix

Revised list of plant names and authority
Acacia albida Delile syn. *Faidherbia albida*
Acacia ehrenbergiana Hayne
Acacia leucopholea (Roxb.) Willd.
Acacia nilotica, (L.) Willd. ex Delile
Acacia Senegal Willd.
Acacia tortillis sub sp. *Raddiana* Hayne
Acer monspessulanum L.
Aeluropus littoralis Parl.
Aeluropus lagopoides (Linn.) Trin. ex Thw.
Alhagi camelorum DC.
Alhagi Lehmanii (Bge) Kuntze
Alhagi pseudalhagi (Bieb.) Fisch
Alnus glutinosa (L.) Gaertn.
Alyssum desertorum Stapf
Ammodendron kavirensis Freitag
Amorpha fruticosa L.
Amygdalus scoparia Spach
Anabasis salsa (C.A. Mey.) Benth. ex Volkens
Anabasis. *Ramosissimum* (Cosson & Durieu) Rothm
Armeniaca vulgare Lam.
Artemisia arenaria DC.
Artemisia aucheri Boiss.
Artemisia diffusa Krasch. ex Poljak
Artemisia halodendron Turcz. ex Besser
Artemisia sieberi Besser

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G.A. Heshmati and V.R. Squires (eds.), *Combating Desertification in Asia, Africa and the Middle East: Proven practices*, DOI 10.1007/978-94-007-6652-5,

(continued)

Revised list of plant names and authority
Artemisia sphaerocephala Krasch
Astragalus adsurgens Pall.
Astragalus gossipinus Fisch. ex Hoh
Astragalus gossypinoides Hand.-Mazz
Atraphaxis bracteata Losinsk.
Atraphaxis pungens (M. Bieb.) Jaub. & Spach
Atriplex amnicola Paul G. Wilson
Atriplex canescens (Pursh) Nutt.
Atriplex halimus L.
Atriplex nitens subsp. *desertorum* Iljin
Atriplex nummularia Lindl.
Atriplex undulate (Moq.) D. Dietr.
Atriplex. Canescens (Pursh) Nuttall
Avicennia germinans L.
Balanites aegyptiaca (L.) Delile,
Bassia hyssopifolia (Pall.) Kuntze
Bauhinia racemosa Lam.
Berberis integerrima Bunge
Borassus aethiopium Mart.
Bromus tectorum L.
Bromus tomentellus Boiss.
Butyrospermum parkii (J. Gaertn.) Hepper, (G. Don)
Cajanus cajan. (L.) Millsp
Calliandra calothyrsus Meissn
Calligonum arborescens Litv.
Calligonum caput-medusae Schrenk
Calligonum leocacladum (Schrenk) .Bge
Calligonum mongolicum Turcz.
Calotropis procera (Willd.) R. Br.
Camphorosma lessingii Litv.
Caragana korshinskii Kom.
Caragana microphylla Lam.
Carex complanata Torr. & Hook.
Carex pachystylis J. Gay
Carissa carandas L.
Carpinus betulus L.
Casuarina equisetifolia L.
Cassia tora L.Syn. *Senna tora* (L.) Roxb

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Revised list of plant names and authority
Cenchrus ciliaris (L.) Link
Ceratoides Ewersmannia (Stschegleev ex Losina-Losinskaja)
Ceratonia siliqua L.
Chloroxylon swietenia DC.
Chrysopogon zeylanicus (Nees) Thwaites
Climacoptera lanata (Pall.) Botsch.
Combretum glutinosum Perr. ex DC.
Commiphora africa (A. Rich.) Engl. (syn. *Heudelotia africana*)
Cydonia oblonga Mill.
Cynodon oblonga L.
Dactylis glomerata L.
Daphne mucronata Royle
Desmodium rensoni (Oerst.) Kuntze
Dichrostachys cinerea (L.) Wright & Arn.
Diospyros ebenum J. Konig ex Retz.
Dipterocarpus zeylanicus Thwaites
Dyospyrus lotus L.
Eichhornia crassipes (Mart.) Solms
Elaeagnus angustifolia L.
Ephedra strobilaceae Bunge
Equisetum ramosissimum Desf
Eucalyptus camaldulensis Dehnh.
Euphorbia antiquorum L.
Euphorbia larica Boiss.
Eurotia ewersmannia Bunge,
Fagus orientalis Lipsky
Festuca ovina L.
Flemingia macrophylla (Willd.) Merr.
Fraxinus rotundifolia Mill.
Gliricidia sepium (Jacq.) Walp.
Glycyrrihiza glabra L.
Halimocnemis occulta (Bunge) Hedge
Halocnemis varia L.
Halocnemum strobilaceum (Pall.) MB
Halostachys caspica C.A. Mey.
Halostachys belangerana (Moq.) Botsch.
Halothamnus subaphyllus (C.A. Mey.) Botsch.
Haloxylon ammodendron (C.A. Mey.) Bunge ex Fenzl

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Revised list of plant names and authority
Haloxylon aphyllum Bunge ex E.Fenzl
Haloxylon persicum Bunge ex Boiss. & Buhse
Haloxylon scoparium Pomel
Hedysarum fruticosum Pall.
Hedysarum laeve Maxim.
Hedysarum scoparium Fisch. & C.A. Mey.
Heliotropium rudbaricum (Bornm.) Riedl
Hippophae rhamnoides L.
Hyphaene thebaica L. *Mart*
Ipomoea pes-caprae L. Roth
Jatropha curcas L.
Juniperus communis L.
Juniperus polycarpos K.Koch
Juniperus sabina L.
Kochia prostrata (L.) Schrad.
Kochia scoparia (L.) Roth
Leptadenia pyrotechnica (Forssk.) Decne.
Lespedeza bicolor Turcz.
Leucaena leucocephala (Lam.) de Wit
Leucaena canescens Benth.
Leucaena diversifolia (Schltdl.) Benth.
Leucosidia sericea Eckl. & Zeyh.
Limonium gmelinii (Willdenow) Kuntze
Lonicera nummulariifolia Jaub. & Spach
Lycium ruthenicum Murr.
Lycium turcomanicum Turcz. ex Miers
Maerua crassifolia Forssk.
Malus domestica Borkh.
Malus silvestris (L.) Mill.
Morus alba L.
Morus nigra L.
Nitraria schoberi L.
Nitraria tangutorum Bobrov
Onobrychis cornuta (L.) Desv.
Opuntia dillenii (Ker Gawl.) Haworth
Opuntia inermis (DC.) DC.
Paliurus spina-christi Mill.
Pandanas tectorius Parkinson ex Du Roi

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Revised list of plant names and authority
Parkia biglobosa (Jacq.) R.Br. ex G.Don
Parkinsonia aculeata L.
Paronychia argentea Lam.
Parrotia persica C.A. Mey.
Peganum harmala L.
Pinus sylvestris var. *mongolica* Litv.
Pistacia atlantica Desf.
Pistacia khinjuk Stocks
Poa bulbosa L.
Poa nigra Clem.ex Willk. & Lange
Populus alba L.
Populus alba var. *pyramidalis* Bunge
Populus canadensis Moench
Populus diversifolia Schrenk syn. *P. euphratica*
Populus euphratica Oliv.
Populus gansuensis C. Wang & H.L. Yang
Populus nigra var. *pyramidalis* Spach
Populus simonii Carriere
Prosopis chilensis L.
Prosopis cineraria (L.) Druce
Prosopis juliflora (Sw.) DC.
Prosopis spicigera L.
Psylliostachys suvorovii (Regel) Roshkova
Pteropyrum aucheri Jaub. & Spach
Punica granatum L.
Pyrus syriaca Boiss.
Quercus brantii Lindl.
Quercus castaneifolia C.A. Mey.
Quercus infectoria G. Olivier
Quercus libani G. Olivier
Quercus boissieri Reuter
Reaumuria soongarica (Pall.) Maxim.
Robinia pseudoacacia L.
Rosa canina L.
Salicornia arbuscula R. Br.
Salicornia herbacea L.
Salicornia paulsenii Litv.
Salix babylonica L.

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Revised list of plant names and authority
Salix flavida Y.L. Chang & Skvortsov
Salix gordejevii Y.L. Chang & Skvortsov
Salix matsudana Koidz.
Salix psammophila C. Wang & Ch Y. Yang
Salsola arbuscula Pall.
Salsola gemmascens Pall.
Salsola orientalis S.G. Gmel.
Salsola paletzkiana Litv.
Salsola paulsenii Litv.
Salsola richteri (Moq.) Karel ex Litv.
Salsola rigida Pall.
Salvadora persica L
Schismus barbatus (Loefl. ex L.) Thell.
Sida cordifolia L.
Spinifex littoreus (Burm.f.) Merr.
Stipagrostis pennata (Trin.) De Winter
Suaeda *aralocaspica* Forssk. ex J.F. Gmel.
Tamarix androssowii Litv.
Tamarix hispida Willd.
Tamarix ramosisima Ledeb.
Tamarix stricta Boiss.
Taxus baccata L.
Thuja occidentalis L.
Tilia rubra DC.
Trifolium pratense L.
Trigonella noeana Boiss.
Typha australis Schumach.
Ulmus glabra Huds.
Ulmus pumila L.
Ziziphus mauritiana Lam
Zizyphus oenoplia (L.) Mill.
Zygophyllum atriplicoides F. et M.
Zygophyllum eurypterum Boiss. & Buhse
Zygophyllum xanthoxylum (Bunge) Engl.

Glossary

a.s.l altitude of a site measured as above mean sea level.
Agrophytocenous plant community created by planting trees in an agricultural landscape
Albedo reflectivity of the earth's surface. Albedo is measured as the fraction of incident light that the surface reflects back in all directions. Removal of vegetation induces a greater albedo effect
Archipeligo doctrine In the Philippines the notion that the islands and the surrounding waters should be regarded as one unit
Argillaceous containing clay particles and maybe mica
Bajadas alluvial fans, accumulation at a foot slope
Barangays In the Philippines is the smallest political unit in the Philippines
Barani rainfed farming
Berebere In Chad and other neighboring countries is the name for millet
Chamaephytes (dwarf-shrubs) are plants that bear hibernating bud on persistent shoots near the ground – woody plants with perennating buds borne close to the ground, no more than 25 cms above soil surface
Chena an area of virgin or secondary timberland in a tropical region cleared and cultivated for only a few years and then abandoned .
Colluvial soil derived from river sediments
Dirhams a unit of currency in Morocco and other Arab speaking countries
Douars In Morocco a village
Dzud In Mongolia a severe winter causing widespread death of livestock
Edificators a plant species having a clearly defined habitat-formation ability, that is, the ability to determine the structure and, to a certain extent, the species composition of a plant community, or phytocoenosis. Edificators have a great effect on the environment and, through it, on the lives of the other plants in the community
El Nino a period of drier seasons induced by changes in sea temperature
Ephemeroides a group of perennial herbaceous plants for which fall-winter-spring vegetation is common. During the dry season the plants remain dormant in the

G.A. Heshmati and V.R. Squires (eds.), *Combating Desertification in Asia, Africa and the Middle East: Proven practices*, DOI 10.1007/978-94-007-6652-5,

form of seeds, bulbs, tubers, or rhizomes. The vegetative period of ephemeroids in arid zones (tulips, sedge, meadow grass) is two to eight months

Falaj an ancient system of irrigation that utilizes ground water

Ghanat a system of sub surface canals that bring water from the mountains

Haloxerophytes salt loving desert plants

***Harmattan* in Niger** a hot dry sandy wind that blows from the north-east in the dry season

Jabals Mountains (Oman)

***Khamaseen* in Morocco** a series of severe dust storms that blow south to north in summer

Kaingin system or swidden cultivation (Philippines)

Lacustrine soils derived from lake beds

Lahar Is a type of lava from a volcano

Law of the sea The United Nations treaty that governs the world's oceans

Luvisols are a characteristic soil of forested regions; identified by the presence of eluvial (Ae) horizons and illuvial (Bt) horizons

Matorral a form of low scrub, common in Mediterranean climate zones

Montreal Protocol is an international agreement on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer)

Pediplain an extensive gently sloping area at the base of hils

Phytoceneosis the species mix that makes up a plant community

piosphere effect Radial attenuation of stocking and grazing pressure from the watering point

Polders low lying tract of land enclosed by embankments

Psammophytes sand loving plants

Pyroclastic materials of volcanic orgin

Ramsar The Convention on Wetlands of International Importance, especially as Waterfowl Habitat) is an international treat

Sandification Sandy desertification that results when the finer soil particles are removed and sand remains

Sodicity soils with high levels of exchangeable sodium

Sodification is the process by which the exchangeable sodium content of the soil is increased.

Solonchaks a type of soil formed usually by the salinization of soils in steppe, desert, and semidesert regions having an exudative water regime, that is, a regime in which salts rise to the upper soil layers owing to the evaporation of groundwater from the surface.

Soums in Mongolia an administrative unit lower than an oblast

Subduction The process by which one crustal block descends beneath another, leading to inundation

Stupa structures erected to honor, commemorate esteemed persons (monks etc.)

Tanoor are traditional ovens used to prepare bread, a staple food in Iran

Takyr a flat clayey tract covered with water in the spring, but in the summer dry, with scant vegetation

Therophytes plant which survive unfavorable seasons in the form of seeds, and completes its life-cycle during favorable seasons. Many desert plants are by necessity therophytes

Wadi a watercourse in N Africa and Arabia, dry except in the rainy season

Xerohalophytes salt tolerant desert plants

Xerophytes plants adapted to growing under dry conditions

Xeropsammophytes sand-loving desert plants

Index

A
Abdou, I., 191–213
Abiotic, 252, 253
Aerial photographs, 298, 300
Aerial seeding, 50, 55
Afforestation, 37, 38, 41, 43, 50, 53–55, 62, 64, 70, 84, 87, 129, 157, 161, 163, 165, 210, 212, 246, 270, 274, 280, 294, 295, 327, 341, 384, 386, 395, 408, 414, 417
Agro-silvi pastoral systems, 250, 262, 269, 270
Alborz Mountains, 358–361
Alexandria, 114, 120–122, 126, 127, 429
Al-Hashmi, H., 401–422
Alkalinization, 12, 119, 195, 262, 271, 284–286, 288, 301
Anthropogenic, 80, 81, 120, 222, 252, 253, 258
Aquifers, 79, 379, 395, 406, 407, 417, 418
Aral Sea, 250, 260
Archipelago doctrine, 192, 304
Armed conflict, 179, 198
Aswan dam, 115, 118, 120, 130
Awareness raising, 12, 18, 107, 133, 135, 182, 226

B
Bajadas, 405, 465
Beneficiaries, 104, 106, 143, 448
Biodiversity, 14, 80–82, 84, 85, 100, 102, 104, 105, 131–135, 150, 156, 167, 196, 200, 240, 243, 244, 253, 269, 297, 299, 313, 327, 336, 338, 341, 344, 345, 351, 374, 383, 441, 449
Biological methods, 49–71, 162–165, 183, 368, 369, 384, 385, 391, 399
Biomass
  above ground, 60, 256, 259, 268
  below ground, 257, 259
Biosaline agriculture, 261–268, 271–275, 396
Brush fences, 183–185

C
Cairo, 115, 119, 429
Camels, 141, 175, 177, 221, 252, 411–414
Capacity building, 106, 130, 135, 149, 204, 225, 397, 446, 455, 459
Carbon, 256–257, 267, 274, 312, 372–374, 388, 390, 406, 441
Carbon isotope analysis ($d^{13}C$), 256–257
Cashmere, 221, 222, 224, 226
Caspian Sea, 356–358, 360–362, 365, 380
Castro, G.M. Jr., 303–320
Changes
  spatial, 87, 257–260, 263, 274
  temporal changes, 88, 257–260, 263, 274
Chena, 328, 330, 465
Climate
  change, 80–81, 85, 87, 107, 110, 113–133, 141, 187, 191, 208, 210, 222, 225, 226, 250, 251, 261, 270, 274, 327, 347, 383, 399, 438
Coastal dunes, 328, 342–345, 406
Coastline, 115, 324, 402
Combat desertification, 14–17, 50, 71, 82, 100–107, 131, 143–146, 151, 158, 181, 182, 186, 188, 203, 206, 208, 215, 226, 234, 249–275, 279–301, 303–320, 333, 351, 391, 396, 399, 408–410, 418, 437, 446, 454
Composting, 285, 312

G.A. Heshmati and V.R. Squires (eds.), *Combating Desertification in Asia, Africa and the Middle East: Proven practices*, DOI 10.1007/978-94-007-6652-5,

Cost/benefit ratio, 6, 16, 438
Crop-livestock systems, 107, 271, 274
Crop rotation, 82, 83, 87, 178, 179, 189, 197, 312, 316, 397

D
Darwish, Kh., 113–136
Deforestation, 12, 18, 81, 84, 85, 103, 144, 181, 183, 185, 206, 210, 232, 240–243, 246, 282, 284, 286–293, 296, 311, 326–328, 338, 339, 380, 381
Demand-driven, 145
Desert
  areal extent of, 292
  attributes, 115, 129
  in China, 3–18, 21–46, 49–71, 430, 441
  development strategy, 295, 419
  encroachment, 22, 50, 83, 85, 180–181, 186, 210, 417, 420–421, 428, 429
  geographic distribution, 4, 77, 79, 218, 219, 357, 422
  margins, 80, 429, 430
Desertification
  abiotic impacts, 253
  human impacts, 10–12, 81, 97–100, 119
Desertified regions, 3–18, 44, 49–71, 115, 243, 428
Desert research Center, 130–131
Djibril, H., 169–189
Donor, 17, 101, 102, 110, 132, 133, 145, 187, 206, 213, 227, 301, 344, 345, 387, 440, 446–448, 450, 451, 453, 457
Dorj, O., 217–228
Drought, 11, 12, 56, 57, 81, 84, 86, 87, 92, 95–97, 101, 108, 124, 141, 143, 144, 147, 156, 174, 176, 180, 181, 183, 186, 187, 192, 196–198, 210–212, 222, 224, 225, 228, 235, 240, 243, 244, 253, 262, 271, 280, 282, 287, 294, 303–320, 325, 326, 328, 330, 333, 338, 346, 358–360, 374, 379, 391, 399, 409, 410, 415, 433, 436
Drought tolerant fodder, 57, 187, 391
Dryland development, 100
Dry Zone, 96, 281–288, 294–297, 299, 301, 324–328
Dry Zone Greening Department (DZGD), 287, 293–296
DSS. *See* Dust and sand storms (DSS)
Dust and sand storms (DSS), 7, 12, 51, 422
DZGD. *See* Dry Zone Greening Department (DZGD)
Dzud, 220, 224, 225, 465

E
Ecological zone, 195, 254, 263, 264, 359, 360, 362, 365
Ecotypes, 367
El Fayoum, 115, 118, 119
El Nino, 124, 316, 320, 465
Enabling environment, 100, 145, 248, 336, 383, 441, 447–449, 452
Enkhbold, M., 217–228
Ethnic tensions, 433, 435
Euphrates, 127
Eutrophication, 327

F
Fallow, 82, 100, 103, 109, 179, 220, 239, 281, 296, 311
Flood waters, 395, 399
Food security, 87, 102, 143, 192, 196, 197, 206, 212, 249–275, 295, 320, 419
Forest, 6, 50, 81, 95, 157, 178, 193, 218, 234, 269, 281, 307, 325, 360, 381, 408, 435
Forestry, 17, 50, 98, 100, 102, 144, 157–160, 177, 181, 183, 185, 195, 197, 198, 208, 238, 244, 287, 294–296, 298, 299, 311, 312, 320, 332, 333, 338, 341, 346, 347, 351, 383, 430, 431
Fuel briquette, 288
Fuel-efficient stoves, 288
Fuelwood, 12, 205–209, 243, 284, 293, 295, 374, 434

G
Game reserves, 142, 176
Gansu Desert Research Institute (GDCRI), 17
Gariola, S., 75–88
GDCRI. *See* Gansu Desert Research Institute (GDCRI)
Geobotanical survey, 254–255, 358–366
GGW. *See* Great Green Wall
Ghanats, 383
Goats, 100, 141, 175, 177, 217, 220–222, 243, 252, 312, 411, 413, 414
Governance, 100, 149, 150, 194, 319, 348–350
Grains, 178, 243, 284, 307
Grassroots, 15, 151, 226, 234, 447, 451
Grazing impacts, 12, 50, 65, 80, 81, 83, 84, 98, 103–106, 108, 109, 125, 142, 150, 151, 155, 157, 158, 160, 183, 198, 224, 227, 238, 240, 242, 243, 250, 252–254, 256–261, 269, 289, 292, 366, 380, 384, 395, 398, 404, 405, 407, 409, 413, 417, 421, 433, 437, 439, 466

Great Green Wall (GGW)
of Africa, 187–188
of China, 50, 51
Greenbelt, 188, 213
Greenhouse gases, 248
Green manure, 87, 146, 148
Green revolution, 246
Groundwater, 7, 78, 80, 85, 120, 124, 127, 147, 198, 261, 273, 285, 287, 290, 333, 379, 395, 399, 406, 407, 417, 466
Gulf of Aqaba, 115
Gulf of Suez, 115, 129
Gully erosion, 156, 208, 290, 292, 327, 382
Gullying, 156, 157, 163, 164, 208, 241, 290–293, 327, 336, 382
Gum arabic, 178, 210

H
Habitat, 6, 82, 105, 106, 155, 197, 199, 221, 238, 242, 243, 248, 269, 270, 288, 290, 297, 307, 319, 328, 338, 355–374, 428, 465, 466
Halophytes, 254, 261–265, 267–271, 273, 274, 361–362, 364, 365, 467
Hammouzaki, Y., 91–110
Heshmati, G.A., 3–18, 21–46, 49–71, 354–375
Holistic, 6, 108, 135, 203, 335, 372, 438
Horses, 7, 177, 252

I
IEM. *See* Integrated ecosystem management (IEM)
Income-generation, 101, 187, 205, 298, 314
Infrastructure, 31, 56, 93, 97, 103, 120, 121, 126, 130, 148, 149, 160, 183, 187, 197, 200, 227, 242, 289, 292, 333, 335, 411, 421, 428, 439, 448
Innovation, 130, 132, 146, 148, 212, 248, 317, 372, 446, 450–452
Institutional change, 132, 149, 348, 451
Integrated ecosystem management (IEM), 6, 201, 438
Iran, 6, 355–374, 377–399, 466
Irrigation, 6, 12, 16, 22, 31, 42, 45, 53, 56, 62, 63, 65, 69, 70, 77–79, 86, 93, 94, 97, 102, 103, 117, 119, 123, 128, 130, 146, 148, 160, 163, 165, 176–178, 207, 210, 232, 235, 237, 238, 240–242, 245, 246, 250–252, 260–261, 271, 273, 274, 281, 286–289, 297, 298, 301, 312, 316, 319, 326, 330, 333, 335, 338, 361, 368, 370, 385, 395, 396, 404, 405, 408, 409, 417, 420, 433, 435, 436, 438, 440, 466
Islands, 221, 304–306, 309, 313, 319, 324, 326, 327, 341, 342, 404, 449, 465
Israel, 16, 114

J
Jatropha plantation, 247

K
Khan, T.N., 231–248

L
Lakes
Lake Chad, 169–189, 193, 198, 201, 465
Lake Moeris, 119
Lake Nasser, 115
Land
allocation, 129, 273, 331, 335, 338
clearing, 198, 288–293, 437
conversion, 313, 430, 432–434, 436
degradation, 5, 78, 92, 117, 144, 156, 179, 199, 222, 233, 248, 282, 307, 326, 379, 408, 428, 446
reclamation, 86, 119, 130–131, 157, 158, 296, 419, 430, 436
use, 6, 12, 60–64, 71, 79, 82, 97, 98, 115–117, 119–122, 125, 127, 129, 146, 148, 150, 158, 167, 172–174, 188, 204, 210, 211, 235, 236, 238–242, 244, 248, 280, 285, 293, 296–300, 308, 311, 313, 320, 325–333, 335, 336, 338, 340, 345, 347, 349, 351, 362, 379–381, 392, 396, 397, 399, 408, 411–416, 420–422, 430, 433–438, 441
Landslides, 289, 297, 327, 333, 338, 345, 347, 441
Laws, 18, 82, 84–86, 144, 182, 201, 225, 226, 296, 298, 313, 327, 330, 332, 341, 348, 349, 383, 391, 397, 421, 466
Lessons learned, 208, 248, 446, 452–453
Libya, 6, 75–88, 114, 171, 185, 193
Li, E.V., 249–275
Livelihoods, 81, 100, 103, 130, 141, 148, 167, 182, 188, 193, 210, 220, 222, 227, 232–233, 243, 297, 312, 327, 334, 342, 345, 372, 373, 441

Livestock, 14, 27, 39, 50, 56, 81, 82, 95–100, 103, 104, 107–110, 125, 141, 142, 148, 150, 151, 155–157, 163, 165, 167, 178, 188, 193, 198, 211, 220–222, 225–228, 232, 238, 240, 242–244, 252, 253, 257, 258, 260, 268–270, 286, 289, 292, 301, 312, 340, 361, 381, 396–398, 411, 413, 414, 417, 433–435, 438, 439, 441, 465
Lkhamyanjin, S., 217–228

M
Master plan, 30 year, 287
Mediterranean climate, 76, 94, 466
Mediterranean coastline, 94, 115, 118, 120, 121, 126
Mediterranean Sea, 76, 79, 92, 94, 95, 114, 115, 120, 172
Medium Term Action Plan (MTAP), 191–213
Mijiddorj, K., 217–228
Mining 18, 48, 147, 224, 333, 385
Mining sites, 265
Modeling, 28, 50, 60–71, 99, 106, 119, 123–125, 166, 183, 255, 256, 259, 260, 262, 270, 299–300, 318, 373, 374, 393, 414, 415, 446, 451, 454
Momou, A., 113–136
Mongolia, 4, 5, 44, 51, 55, 62, 63, 67, 217–228, 429, 432, 437–439, 465, 466
Monsoon, 195, 243, 244, 281, 284, 314, 328, 403, 404, 411, 414
Moshoeshoe, S., 153–167
MTAP. *See* Medium Term Action Plan (MTAP)
Myanmar, 4, 279–301

N
National parks, 84, 142, 150, 176, 196, 363
Natural disasters, 289, 292
Natural resource base, 108, 141, 225, 249–275, 282, 334
NDVI. *See* Normalized Difference Vegetation Index (NDVI)
Nejad, A.N., 377–399
Nguru, P.M., 139–151
Nile
  Delta, 115, 118–122, 128
  River, 115, 119, 123, 124, 126
Non-food crops, 307
Normalized Difference Vegetation Index (NDVI), 223, 256, 259, 410
Nosmoo, A., 217–228
Nursery, 51–54, 65, 84, 157, 184, 185, 211, 243, 367–368, 372, 373, 387

O
Oasis, 23, 60, 61, 119, 205, 431, 433, 435, 438, 439
Off-site effects, 94, 292, 340, 347
Olives, 61, 77, 361
Ostriches, 175, 208

P
Palms, 100, 174–177, 183, 186, 195, 320, 404, 405, 422
Pasturelands, 11, 85, 86, 185, 200, 222, 224, 226
Patana grass, 328, 329
Permafrost, 224
Physiogeography, 59–60, 140, 143, 154, 195, 359, 404–407
Pilot project, 393, 421, 446, 459
Piosphere, 254, 256, 257, 259, 260, 466
Plant distribution, 59, 208, 256, 261, 262, 271, 274, 309, 319, 355–374, 431, 438
Plant species, 7, 22, 53–60, 71, 82, 176, 187, 224, 253, 256, 262, 274, 298, 355–374, 388, 436, 461–465
Plastic mulching, 50
Population pressure, 198, 328, 398
Poverty
  alleviation, 100, 143, 145, 167, 274, 275, 320
  incidence, 141, 320
Pre-adapted species, 387
Puntsagnamil, M., 217–228

R
Radial attenuation of stocking pressure, 257, 466
Rafiq, M.K., 231–248
Rajabov, T.F., 249–275
Rangelands, 12, 50, 83, 92, 130, 141, 156, 197, 222, 232, 252, 362, 379, 404, 428
Red Crescent, 192, 196
Red Cross, 192, 196, 210
Red Sea, 114, 115, 120, 127, 172
Reforestation, 83, 84, 103, 149, 188, 201, 204–206, 208, 210, 280, 294–296, 340
Regulations, 18, 82–86, 118, 132, 133, 180, 181, 188, 198, 210, 225–226, 296–297, 336, 340, 383, 387, 397, 441, 448, 449
Remediation, 110, 160, 274
Remediation efforts, 217–228, 245–247
Replication, 185, 248, 255, 314, 399, 445–459

Resources-utilization, 18, 130, 151, 208, 238, 274, 281–282, 287, 295, 301, 331, 342, 351, 399, 416, 421, 455
Restocking, 149
Revegetation
strategies, 147, 274
techniques, 147, 387
Rice, 50, 178, 179, 283, 285, 286, 288, 311, 312, 316, 319, 325
Rono, D.K., 139–151
Rosetta, 115, 122, 126
Rubber, 325–327, 329, 336, 339–341
Runoff, 124, 147, 162, 163, 284, 285, 292, 308, 347, 380, 393, 398
Rural poor, 235, 271, 274

S
Saad, A.M., 75–88
Safaa, M., 113–136
Saharan, 94, 95, 97, 127, 174–175, 177, 195
Sainjargal, U., 217–228
Saleh, S.A., 113–136
Saline soils, 250, 261, 264, 270, 274, 284, 288, 364
Salinity
gradient, 254–267, 270, 271
Salinization, 10, 12, 18, 82, 87, 119, 120, 124–127, 146, 195, 232, 240, 241, 243–244, 249–275, 284–286, 288, 289, 301, 326, 328, 335, 381, 385, 395, 406, 408, 420, 430, 434, 466
SALT, 297, 312–315, 345
Salt affected lands, 260–264
Salt-tolerant species, 256, 265, 268–271, 274
Sand dune
fixation, 27, 50, 82, 131, 133, 208–210, 367, 390, 391, 396, 398, 399
Sand encroachment, 13, 17, 45, 60, 65, 71, 81, 182–185, 200, 210, 430–432
Sandification, 437, 466
Sands
biological methods, 50, 51, 53–71, 183, 385
controlling, 16, 17, 21–46, 55, 62, 65, 208, 430
mechanical measures, 21–46, 50, 51, 56
movement of, 12, 18, 21–46, 65, 70, 126, 200, 224, 242, 367, 431
Scale, 9, 28, 55, 78, 133–134, 165, 183, 210, 212, 248, 254, 255, 265, 270, 274, 298, 299, 314, 333, 387, 390, 414, 433, 439, 446, 447, 450, 452, 454, 455
Scaling-up, 185, 425, 445–459
Sea level rise (SLR), 120–125, 127, 128
Sea water incursions, 80, 128, 285, 347, 406
Seed increase, 52, 84, 268, 273
Sekantsi, M., 153–167
Shahbaz, M., 231–248
Shapotou Desert Research Station, 46
Shariff, N.M., 75–88
Shaumarov, M., 249–275
Shelter belts, 15, 16, 44, 46, 50, 66, 67, 71, 87, 197, 210, 245, 269, 271, 384, 421, 422, 428
Shelter forest, 62, 63, 66
Shuyskaya, E.V., 249–275
Sinai Peninsular, 115
Slash and burn, 178, 289, 295, 327, 330
SLM. *See* Sustainable land management (SLM)
SLR. *See* Sea level rise (SLR)
Small-holders, 274, 312, 314, 408
Snow melt, 11, 361, 432, 434
Sodicity, 232, 240, 241, 271, 440, 466
Soil erosion, 6, 12, 78, 82, 93, 98, 99, 107, 109, 126, 127, 156, 160, 238, 240–244, 284, 288, 289, 297, 299, 300, 308–310, 312, 314, 315, 326, 327, 329, 330, 333–338, 340–342, 345, 347, 379–381, 396, 399, 404, 407, 417, 428, 438
Squires, V.R., 3–18, 65, 227, 427–441, 445–459
Sri Lanka, 323–351
Steppe, 11, 55, 60, 67, 97, 178, 195, 218, 221–223, 252, 284, 287, 360, 362–364, 466
Strategic partnerships, 446
Sudan, 114, 115, 130, 171, 172, 185, 187, 195
Sustainable development, 14, 15, 17, 88, 109, 120, 128, 135, 136, 143, 145, 146, 181, 208, 212, 225, 290, 294, 295, 298, 327, 328, 348, 350, 410, 419, 422, 429, 452
Sustainable land management (SLM), 103, 205, 211, 212, 248

T
Taming the desert, 17, 432–433, 438
Tea, 324–329, 335, 336, 339, 341, 345
Temperature rise, 124, 347
Toderich, K.N., 249–275, 396
Top-down, 145, 372
Topsoils, 147, 156, 197, 260, 285, 299, 308
TOT. *See* Training of trainers (TOT)
Tourism, 80, 94, 99, 119–122, 126, 141, 148, 297, 381

Tragedy of the commons, 153
Training of trainers (TOT), 455
Transferability, 131–134, 148, 149, 182, 281, 288, 300, 316, 446, 449, 451, 452, 456, 458
Transformational goals, 449–452
Transhumance, 98, 147, 148, 178
Transport corridors
  canals, 22
  highways, 64, 65, 67–68
  railways, 64–67

U
UNCCD. *See* United Nations Convention to Combat Desertifition (UNCCD)
United Nations Convention to Combat Desertifition (UNCCD), 5, 15, 71, 87, 100, 101, 131, 133, 151, 167, 212, 225, 233, 234, 238, 253, 294, 317, 320, 326, 333, 348, 397, 410, 419, 422, 144, 149
Uplands, 219, 280, 282, 308, 311–312, 315, 316, 319, 324–326, 333, 340, 380, 390

V
Vegetables, 17, 77, 178, 207, 220, 283, 312, 314, 335, 404–406, 408
Volcano, 156, 173, 307, 309, 311, 360, 466

W
War, 176, 180, 192
Water
  conservation, 10–12, 130, 386
  deficits, 78, 86, 195, 232, 267, 358, 393
  erosion, 9, 10, 14, 87, 109, 147, 156, 199, 212, 224, 232, 240–242, 285, 289, 298, 299, 301, 308, 329, 381
  scarcity, 76, 86, 87, 102, 127, 196, 235, 297, 326, 405–408, 421, 439
  shortage, 14, 125, 127, 297, 301, 358, 411
  spreading, 81, 130, 147, 187, 287, 340, 347, 393, 395, 399
Waterlogging, 119, 243, 244, 262, 270, 275
Watershed, 50, 160–162, 165–166, 173, 196, 197, 200, 210, 232, 243, 288–290, 292, 293, 295, 299, 318–320, 327, 331, 332, 335, 341, 342, 344, 345, 379, 380, 385, 387, 388, 390, 396–397, 399, 421
Weerasinghe, R.P.M., 323–351
Weine, N.N.O., 279–301
Wetlands, 120, 167, 176, 196, 280–282, 327, 338, 466
Wildlife, 84, 141, 145, 150, 221, 298, 319, 328, 338, 410
Wind power, 129

X
Xerophytes, 254, 263, 265, 467

Y
Yoshiko, K., 249–275

Z
Zagros mountains, 362