Desertification and Land Degradation

Concept to Combating

Ajai
Rimjhim Bhatnagar

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Dedicated to our parents

Mr. Ramesh Kumar

Mrs. Shanti Devi

Mr. Jagdish Swaroop Bhatnagar

Mrs. Asha Bhatnagar

Contents

Foreword

Desertification and land degradation (DLD) are considered major global change issues. The United Nations' Sustainable Development Goal 15 (SDG 15) contends that "desertification affects as much as one-sixth of the world's population, seventy percent of all drylands, and one-quarter of the total land area of the world." Consequently, DLD is a vital societal concern because of its impacts on human populations (e.g., food security and economics) and environment quality (e.g., dust storms, soil erosion, and nutrient depletion). Similar to climate change and biodiversity, DLD is the subject of an international framework convention, The Convention to Combat Desertification (CCD), the aim of which is to "target poverty, drought and food insecurity in dryland countries experiencing desertification, particularly those in Africa."

While CCD was established by the United Nations "in order to facilitate the role of national governments in enacting policies to combat DLD," progress has been hindered by many obstacles and challenges. This book by Professors Ajai and Bhatnagar provides the reader with an admirable overview of the many facets of DLD that constitute these obstacles and challenges, including: How will land change occur worldwide over the next several decades? What will be the main drivers? What will be the environmental and social impacts? What areas are the most vulnerable to DLD? Can suitable indicators be established to monitor change? What global initiatives exist for combating DLD? Can land degradation neutrality be achieved? What kind of land and soil restoration projects yield the most benefits?

This book examines many of the conceptual, methodological and technological advances that have been made during the past several decades to aid in developing appropriate strategies for combating DLD. DLD is shown to have numerous underlying causes, which involve a complex interplay among biophysical and social–economic variables. There is an emphasis on the need to address all socioeconomic levels (local, regional, national, international) in the development of effective DLD policy decisions, as well as the role of integrated research programs that help define causal links, from climate dynamics to ecological impacts to policy response strategies. Of course, the challenges are enormous but so is the need for urgent action to understand and manage desertification and land degradation worldwide.

The authors cite the Dutch saying that "Fertilizer is good for the father and bad for the sons." This simple statement contains numerous powerful messages. For example, research has shown that chemical nitrogen fertilization may be a double-edged sword since it can deplete soil organic carbon and nitrogen due to the acceleration of soil organic matter mineralization, thereby decreasing soil productivity and, ultimately, the efficiency of N fertilization. This complex, nonlinear feedback system is symbolic of a recurring theme throughout this book: that desertification and land degradation are complex issues! In fact, DLD is often considered to be a "wicked problem," that is, a problem that is multifaceted, often open-ended, scale-dependent and certainly not amenable to simple solutions. As the reader works through the chapters, it's easy to see why this is the case: DLD issues involve interactions between ecological, social, political, cultural and economic drivers; these drivers (plus their impacts and consequences) operate at different temporal and spatial scales; and there are multiple actors and stakeholders (including smallholders, policymakers, managers, politicians, etc.), all of which have differing interests and needs.

Desertification and Land Degradation helps the reader negotiate through this complexity, effectively providing a roadmap with many points of interest highlighted along the way. This is an important contribution considering the magnitude of challenges contained in SDG 15: to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss."

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Preface

Desertification and land degradation (DLD) are amongst the most important environmental and social issues that the world is facing at present. Driven by both anthropogenic and natural factors, land degradation has affected about 2.6 billion people in more than 100 countries globally with up to 1.5 billion people at risk.

A lot of emphasis has been given to tackle this geo-environmental problem at the local, national, regional and global level during the recent time, and more so, after the United Nations Convention to Combat Desertification (UNCCD) came into force in the year 1996. Since then, a large number of countries all across the world have tried to address the issues related to desertification and land degradation either by integrating the required plans and actions in their ongoing programmes, related to land use planning, sustainable land management and watershed development programmes etc., or by formulating a separate national action program (NAP) towards combating desertification and land degradation. During the above period of two and a half decades, a large amount of research and development has also taken place in the field of DLD, which were required to address some of the key issues related to combating DLD, e.g. (i) identification and mapping of affected and vulnerable areas, (ii) development of methodology for inventory and mapping of land degradation processes using satellite images, (iii) geospatial techniques for the generation of locale-specific action plans towards preventing and arresting land degradation as well as restoration/rehabilitation of degraded land and (iv) assessment of the impact of the response actions on the ecosystem functions and services as well as on the human well-being and the social systems. A large number of research papers and reports have been published on the techniques, applications and results on the above-mentioned elements of DLD.

Land degradation, being a complex geo-environmental phenomenon involving the bio-physical and social spheres, encompasses a number of disciplines pertaining to physical and biological sciences. As a result, one can find the details on the different elements of DLD in different books (e.g. geography, geomorphology, geology, soils, environmental science and social science) and not in one place. But what is really required by the students, researchers, teachers, natural resource managers and DLD professionals is the availability of details on each and every aspect of DLD in one single place. However, there is hardly any book presently available, which provides comprehensive details on each aspect of desertification and land degradation. Our own experience, while working in the field of desertification and land degradation during the past three decades, has been the same. Lack of the availability of such a comprehensive book has made our lives difficult, especially during the initial and learning phases of our professional careers. Later on, the same difficulty was faced by our students, researchers and project personals working in the field of DLD, and that has motivated us to write this book, which provides comprehensive details on all aspects of desertification and land degradation including the recent technological developments.

This book is an attempt to present the details on all the elements of DLD, from fundamental concepts to the combating actions, which could be helpful to the readers irrespective of the discipline from which they have graduated. Therefore, our thrust has been to make concepts clear in an as simple and comprehensive manner as possible. Topics covered include (i) processes of land degradation, (ii) its causes and drivers, (iii) impact of DLD

on the environment, human well-being and social system, (iv) indicators and conceptual framework, (v) methods for identification of affected and vulnerable areas, (vi) mapping and monitoring techniques and (vii) methods for combating DLD and implementation mechanisms.

In the recent past, remote sensing and geospatial techniques have emerged as powerful tools for mapping and monitoring natural resources as well as studying the Earth's surface characteristics and processes. During the past three decades, the availability of high spatial resolutions data from remote sensing satellites has greatly facilitated mapping, monitoring and combating DLD and thus added a new dimension to the DLD studies. Therefore, a chapter on remote sensing techniques has been included. Like terrestrial desert and desertification, ocean biological deserts and declining marine productivity have become a matter of increasing concern during the recent past. A chapter on ocean biological desert is also included. In addition, chapters on UNCCD's Land Degradation Neutrality as well as the international programmes and efforts towards combating DLD have also been included in the book.

The content of this book will be helpful to those interested in pursuing study or research in the field of desertification and land degradation, as well as to the professionals working in land use planning, sustainable land management and combating desertification and land degradation.

We are grateful to Dr George Joseph, Padma Bhusan, for encouraging us to write this book and for his guidance and support from time to time, and especially in writing the chapter on Remote Sensing Techniques. Our special thanks to Dr R. P. Dubey for meticulously going through the manuscript and giving valuable suggestions and Amit Kushwaha for his help in generating a number of thematic maps and outputs through the analysis of satellite data.

We are thankful to a number of individuals who have helped in various ways to complete this book: Dr. Nilesh M. Desai, Dr. I. M. Bahuguna, Dr Bimal K. Bhattacharya, Dr Mini Raman, Dr R. S. Dwivedi, Dr P. S. Dhinwa, Dr A. S. Arya, Dr Markand P. Oza, Dr Shashi Kant Sharma, Dr Gaurav Jain, Dr Praveen Kumar, Ajay Tiwari, Dr S. A. R. Shah, Dr P. C. Moharana, Dr Kasturi Chakraborty and Dr Sara Minali.

We express our sincere gratitude to Prof James F. Reynolds for writing the foreword for this book.

We also extend our thanks to the Senior Publisher Dr Gagandeep Singh for his cooperation and consistent support and Ms. Jayanthi Chander for the excellent editing, which has given the content of the book a new look.

Our families deserve special appreciation for their patient understanding and excellent support during the preparation of this book.

Ajai

Rimjhim Bhatnagar

Author Biographies

Prof Ajai started his career in 1978 at Space Applications Centre of Indian Space Research Organization (ISRO) and served it for 42 years in various capacities including Group Director, Project Director, Program Coordinator, Professor and Emeritus Scientist. At ISRO, he has developed and operationalized techniques, based on space data and geospatial technology, for inventory, monitoring and combating desertification and land degradation, as well as for watershed development and sustainable land management. He has led the national team which carried out the first-ever land degradation and desertification status mapping of India.

He was India's national coordinator for Asian TPN-1 (Desertification Monitoring and Assessment) of UNCCD and has been instrumental in evolving and standardizing the indicator system and methodology for land degradation and desertification mapping for Asia and India. He has served as the Asian regional expert as well as Consultant to UNCCD from time to time, during the past two decades. Professor Ajai has been on the advisory committee and an author of World Atlas of Desertification – 3rd Edition (WAD-3), brought out jointly by UNCCD, UNEP and European Commission in 2018.

Professor Ajai is Fellow of the National Academy of Sciences and recipient of several prestigious awards, including the Bhaskara Award, William Dixon West Award, GEO-LDN Prize and National Geomatics Award for Excellence.

Dr Rimjhim Bhatnagar has two decades of experience in the field of natural resources management and desertification and land degradation. She joined Space Applications Centre, Indian Space Research Organization (ISRO) in 2004, where she has done pioneering work on the various aspects of land degradation and desertification, including regional and national level mapping, monitoring as well as the development of models for desertification vulnerability assessment using space data and geospatial technology. She has been responsible for the development of models towards the identification of desertification hotspots and bright spots which are vital in formulating and implementing the combating strategies. Dr Rimjhim Bhatnagar has also developed techniques, based on the space-based ocean colour data, for identification, mapping and assessment of ocean biological deserts.

She has authored more than 40 scientific papers, scientific reports, atlases and chapters in books and has a keen interest in writing popular science articles as well. She is a recipient of the prestigious Young Scientist award by the Indian Science Congress Association. Being passionate towards sustainable development, her research work focuses on developing cutting-edge models and techniques in both terrestrial and marine ecosystems.

1

Introduction and Historical Perspective

World's first empire, Akkadian empire in Mesopotamia, established approximately 4300 years ago, disappeared just after a century of prosperity, because of land degradation, desertification and drought.

1.1 Introduction

'Rule life in the Dust Bowl of the continent – if it rains' wrote Mr Robert Geiger, a reporter with Associated Press, on 15 April 1935 (the day succeeding the Black Sunday that witnessed devastating dust storm), to describe the plight of people who have been facing the frequent and severe dust storms in the Great Plains. Successive severe droughts since 1930, coupled with the misuse of land that resulted in soil erosion, have led to the occurrence of frequent dust storms in the region. Even after more than 80 years of 'dust bowl' events, the above topic remains as important and worrisome as it was; the British Broadcasting Corporation reported on 12 November 2015, 'Desertification: The people whose land is turning to dust!', to describe the plight of the people living in northern Senegal, whose life has become extremely difficult due to lack of rains, where vegetation has severely degraded, aridity has increased and the pace of soil erosion has increased during the past 6–7 decades. Similar is the situation in many parts of the world.

1.2 Desertification and Land Degradation – A Global Issue

Desertification and land degradation (DLD) has become one of the most serious environmental and social concerns that the world is facing at present. As per the UN estimates, DLD has affected around 2.6 billion people in more than 100 countries globally, with up to 1.5 billion people at risk. It has influenced over 33% of the Earth's land surface; every year about 12 Mha of land is lost to land degradation, and this rate is increasing (www.unccd.int). Globally, the livelihoods of more than 1,000 million people are estimated to be at risk from DLD, which may eventually drive about 135 million people off their land (UNCCD 2008). Though a large number of countries across the world are affected by desertification and land degradation, it is the poor and developing countries, especially from Africa, Asia and South America, which have been suffering the most. It is estimated that more than 45% of the geographic area of Africa is affected by desertification, and out of this, around 55% is at a very high to high risk of further degradation (Stavi and Lal 2015). Presently,

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in Asia, 38 out of 48 countries are affected by desertification (Pravalie 2016, Mirzabaev et al. 2019). As per the estimate provided by the European Environmental Agency, about 40 Mha or 23% of the European Union territory (mostly in Spain, Cyprus, Greece, Portugal, Bulgaria, Italy and Romania) had 'moderate' to 'very high' sensitivity to desertification (Pravalie et al. 2017, ECA 2018, Mirzabaev et al. 2019). In Russia, about 7% or 130 Mha of the total geographic area was threatened by desertification at the beginning of the 2000s (Kust et al. 2011, Mirzabaev et al. 2019).

An estimated 1.5 billion people inhabit and depend on degraded land (UNCCD 2015), thereby further exacerbating the condition of the land, its natural resources and the ecosystem. Health and productivity of land have been declining during the past decades, while the demand for land-based natural resources has been increasing because of the increasing population (Orr et al. 2017). Land degradation affects not only human wellbeing but also biological diversity, ecosystem goods and services, environment as well as climate. In terms of the economic losses, land degradation has been costing the world an estimated 10– 17% of the global Gross Domestic Product annually (IPBES 2018). Land degradation-associated cost of human wellbeing is not only in terms of money but also includes the negative outcome of health, social cohesion as well as the impact on local management practices.

1.3 What Is DLD?

The process of desertification is not the advancement or movement of deserts across the landscapes and engulfing the fertile land, though it can include the sand deposition and encroachment of sand dunes over land. Rather, it is the degradation of the land of any type happening in drylands. Land degradation refers to the reduction or loss of the biological or economic productivity of land (UNCCD 1994). Desertification can be considered as a subset of land degradation, occurring in dryland areas (arid, semi-arid and dry sub-humid), resulting from various factors, including climatic variations and human activities (UNCCD 1994). However, land degradation occurs in all climatic environments. Desertification and land degradation can and do occur in areas far away from the climatic deserts.

1.4 Causes of DLD

Human actions which can directly cause land degradation include land use change, land conversion (e.g. forest to agriculture or pastureland / agriculture to urban, etc.), cultivation on marginal land, deforestation and unsustainable land management practices. Climate change can exacerbate desertification and land degradation processes through the increase in drought frequency and severity, high aridity, wind, increase in rainfall intensity, flooding, sea-level rise, heat stress, permafrost thaw, among others (Olsson et al. 2019). There has been a general misconception that droughts are always responsible for desertification. Persistent droughts do increase the likelihood of an increase in land degradation rate, especially in non-irrigated agricultural land if the carrying capacity is exceeded or proper

management practices are not followed. Persistent droughts may lead to desiccation which makes the land more vulnerable to degradation. If severe droughts persist and continue to occur for a very long period of time (say, for several decades), making the area devoid of natural vegetation, the area becomes highly vulnerable to soil erosion and also depletion of soil organic carbon and nutrients. In such a situation, the occurrence of high wind will lead to surface soil erosion and may also give rise to sand and dust storms. Appropriately managed land, usually, recovers from droughts with minimal adverse effects when the normal rains return.

The land which is considered to include vegetation, soil and landforms, other biotas, and ecological and hydrological processes that operate within the system can get degraded in a number of ways (UNCCD 1994). There are various types of land degradation processes occurring on the land surface, such as vegetal degradation, soil erosion due to water and wind, salinization and alkalization of soils, waterlogging, soil sealing and urbanization, mass movement, frost heaving and frost shattering. These processes can occur either alone or in combination, for example, vegetal degradation and soil erosion can occur simultaneously in a particular area. Land degradation processes, such as soil erosion due to wind and water, would have started taking place concurrently with the process of soil formation through weathering. Both soil formation and soil erosion are natural processes and usually take place almost at the same time. However, it becomes a matter of concern if the rate of soil erosion equals or exceeds the rate of soil formation. Such kind of surface soil erosion, called accelerated soil erosion, often leads to land degradation. Accelerated soil erosion takes place, mostly due to human actions, including agricultural and pastoral activities, land conversion, deforestation, land use change and non-sustainable land management practices and hence also called human-induced soil erosion. If we talk about soil erosion from agricultural fields, the rate of soil loss due to erosion from conventionally tilled land can exceed the rate of soil formation by a factor of more than two (Olsson et al. 2019). In addition, there are other issues related to agricultural management practices in the context of land degradation.

1.5 Consequences of DLD

Land degradation exacerbates the quality of land, leading to a decline in its biological or economic productivity and thus affecting the livelihood of the people. It not only leads to a reduction in land productivity but also results in the decline in the ecosystem goods and services that are essential for human beings, cattle and other animals for their survival. As the majority of people depend on land-based natural capitals to derive terrestrial ecosystem goods and services for their livelihood, land degradation, therefore, poses a significant challenge for food security and human wellbeing all over the world. Ecosystem goods and services refer to the benefits people derive from ecosystems, including food, clean water, timber, fibre, etc., while natural capital is the stock of natural resources from which goods and services can be extracted and the flow of ecosystem services is maintained. It includes the soil and its properties (physical, chemical and biological), geomorphology, biota and hydrological features that interact among each other, as well as with climate, to determine the quantity and nature of ecosystem services offered by the land. DLD affects both.

Desertification and land degradation can also fuel social, economic and political tensions and unrest that can trigger migration, conflicts and widespread human rights

violations and exacerbate poverty. There are examples of large-scale migration of people due to dried-up resources as a result of serious drought and desertification conditions. Desertification has also created millions of so-called 'environmental refugees', people who are forced to abandon their land, because it can no longer support them for their livelihood (Burns 1995). International Panel on Climate Change (IPCC) has estimated that the number of 'Environmental Refugees' may touch the figure of 150 million by 2050 (UNCCD 2008). These environmental refugees are compelled to leave behind their houses and other properties and migrate, either temporarily or permanently, to other areas in search of livelihood. Such migration can be to a place either within the country or in the neighbouring countries. Desertification-induced forced migration has also given rise to unrest and political strife in many nations of the dryland region. This is in addition to the personal tragedy that compelled migration inflicts on its victims. Competition over resources among local people and migrants, living in a particular area, often leads to scarcities and depletion of resources and can create political and social tension which may further deteriorate into conflicts, as competition intensifies (UNCCD 2008). Desertification and land degradation exacerbate climate change through different mechanisms such as a decrease in vegetation cover, an increase in sand and dust aerosols, and an increase in greenhouse gases. Desertification and land degradation also lead to change in the land surface albedo, thereby affecting the surface energy balance and the associated change in surface temperature, producing negative feedback on climate change (Mirzabaev et al. 2019). Through the change in the status of vegetation cover and soil conditions, desertification also leads to change in the absorption and release of associated greenhouse gasses. Decrease in vegetation cover and drying up of the land surface also increases the frequency of sand and dust storms.

1.6 Historical Perspective

The problems of DLD are not new but have been occurring and affecting millions of people even in historical and ancient times. However, the term 'desertification' was first used by Lavauden in 1927 to describe severely overgrazed lands in Tunisia (Dregne 2000). Subsequent to that, it was used again in 1948 by Aubreville (1949) to describe how tropical forest regions of Africa were being transformed into 'desert like regions' because of deforestation and excessive soil erosion. Human-induced soil erosion or accelerated soil erosion can be said to be at least as old as agriculture. Although human habitation extends back over many thousands of years, the introduction of irrigation and other forms of management practices adopted for agriculture intensification has been responsible for more serious forms of land degradation including waterlogging, salinization, alkalization and soil erosion. Lowdermilk (1953) writes in his book *Conquest of the Land Through Seven Thousand Years*, 'Agriculture has its beginning at least seven thousand years back in two great centres – the alluvial plains of Mesopotamia and the valley of Nile in Egypt'. The above book is based on his own experience and findings of a field survey on land use carried out by him during 1938–1939. His field survey mission was aimed to find out if the lesson learnt from the experiences of these older civilizations could help in solving the serious issues of land degradation, soil erosion and land use problems in the United States, which was struggling at that time to find out a solution to the serious problem of soil erosion in the Great Plains. In Mesopotamia, agriculture developed over a period of time, starting

from unirrigated to irrigated agriculture systems. Mesopotamia is the area between the Euphrates and Tigris rivers, north or northwest of the bottleneck at Baghdad in modern Iraq (http://www.britanica.com/place/Mesopotamia). Flood irrigation was introduced in these alluvial plains having semi-arid climates, which resulted in the production of food crops much more than their own need. This led to the release of their fellows for the division of labour, who became available for other work, which gave rise to what we call 'the development of civilization' (Lowdermilk 1953). Like Mesopotamia, in the Nile valley of Egypt also, agriculture developed with flood irrigation. As per Lowdermilk (1953), perhaps, it was the Nile valley that the practice of ploughing through an ox was used by a farmer about 6,000 years ago (BP-Before present). Ploughing of agricultural fields, in the absence of appropriate management practice, accelerates the process of soil erosion by wind and water. Therefore, the history of accelerated soil erosion as a result of ploughing of the farmland (tillage) goes back to as early as 6,000 years from now.

In fact, some of the ancient civilizations have disappeared as a result of severe and prolonged drought, desertification and land degradation (Lowdermilk 1953, Burns 1995). It has been reported that the world's first empire, the Akkadian, based in southern Mesopotamia, collapsed around 4,200 years ago, after only a century of prosperity, as a result of severe and prolonged drought, land degradation and desertification (Jacobsen and Adams 1958, NYT 1993, Weiss et al. 1993, Burns 1995). It was mainly due to the abrupt climate change in the region (Weiss et al. 1993). The Akkadian was established in Mesopotamia approximately 4,300 years ago after its ruler Sargon Akkad united a number of independent city states. The Akkadian Empire spread along the Tigris and Euphrates rivers, which is presently eastern Syria, south-eastern Turkey and Iraq. Sumer, inhabited by Sumerians, was located in the south of the Akkad region (http://www.britanica.com/place/Akkad). The other primary causes of land degradation in some parts of Mesopotamia, the irrigated agriculture land in Tigris and Euphrates river systems, were siltation in irrigation canals, waterlogging and salinization. Siltation in irrigation canals was primarily due to soil erosion in the catchments of the above-mentioned rivers, while waterlogging and salinization were mainly due to faulty irrigation practices adopted by the people (Jacobsen and Adams 1958, Dregne 1982, 1986, Burns 1995, Arthur 2000). During the above period, increased aridity, high wind and heavy aeolian loss of soils caused the abandonment of Tell Leilan, one of the three large third-millennium cities on the Habur plains (Weiss et al. 1993). Due to increased soil salinity, the main crop – wheat, grown in the areas covered by Tigris and Euphrates river systems, was initially replaced by the salt-tolerant crop barley (Jacobsen and Adams 1958). However, with time, as the soil salinity further increased, the productivity of barley crop also declined drastically to a level that it became an unviable option for cultivation, leading to heavy scarcity of food grains, and as a result of that, the population of the kingdoms of Sumer and Akkad had to abandon the area (Arthur 2000, Shahid et al. 2018). Thus, one of the major causes attributed to the fall of Sumerian civilization had been soil salinization resulting from the faulty irrigation system coupled with the prolonged drought in the Mesopotamian region (Shahid et al. 2018).

The decline of Harappan civilization is also said to have occurred due to changes in climatic patterns, including prolonged drought, rise in temperature and high aridity. More than 4,000 years ago, the Harappan civilization thrived in the Indus River Valley (now Pakistan and north-western India). As per the study reported by Giosan et al. (2018), during 4,300–4,000 BP, a shift in the temperature and weather pattern over the region caused summer monsoon rain to gradually dry up, thus, making agriculture difficult or impossible. During this period the winter monsoon increased (Giosan et al.

2018). By 3800 BP, due to dry conditions, people abandoned their cities and migrated to the smaller villages in the foothills of the Himalayas. However, the winter monsoon also declined 3,300 and 3,000 BP, which would have played a major role in the demise of rural late Harappans.

Mesopotamian and the Indus valley civilizations were not the only ones where land degradation, desertification and drought had made their impact on the people, DLD has been affecting the people in many other parts of the world. Some of them are discussed below.

Lowdermilk (1953), during his field survey in 1938–1939, found Jerash town of Decapolis in Syria/Jordan, once a powerful city of Greek and Roman Culture, buried to a depth of 12 feet. It was buried under the sediments washed away from the eroding slope due to soil erosion. During Roman times, this area supplied grains in Rome and supported thriving communities and rich villas (Lowdermilk 1953).

In the Viru Valley of Peru, South America, irrigated agriculture began sometime between 800 BC and 30 AD (Shahid et al. 2018). The population of this valley attained its peak at around 800 AD, which started declining from 1200 AD. It happened, mainly, because a large number of people started shifting from the densely populated valley to the upper reaches as a consequence of increased soil salinity and rising water table (Shahid et al. 2018).

In Mexico, human-induced soil erosion has been found to occur even much before the Spanish Conquest in 1521 AD (O'Hara et al. 1993, Middleton and Thomas 1997). This was attributed to the extensive land clearing for cultivation during about 3500–350 years BP (pertaining to Preclassic to Postclassic periods). The above findings, reported by O'Hara et al. (1993) were based on the analysis of the sediment cores from the Pátzcuaro Lake in the closed Intermontane basin in the highlands of Michoacán, western Mexico. Pátzcuaro basin has been inhabited since about 5000 years BP years ago and maize-based agriculture was adopted around 3,500 years bp (Watts and Bradbury 1982, Farshad and Barrera-Bassols 2003). The basin, surrounded by high volcanic sierras with short and steep slopes, received more than 1,000 mm of mean annual rainfall. It has been reported that just before the Spanish Conquest in 1521, this area pertained to the Empire of Purépecha (Tarascan) having a population of about 60,000–105,000. Based on the sediment core dating, O'Hara et al. (1993) have reported that the soil erosion rates during both the late Preclassic/Early Classic periods (2500–1200 years BP) and the later Postclassic periods (850–350 years BP) were not lower than those after the Spanish Conquest. Thus, the accelerated soil erosion had been taking place in western Mexico as early as 2500–1200 years BP. Subsequently, Farshad and Barrera-Bassols (2003) also studied this basin and reported that during the period 3600–3100 years BP (coinciding with initiation of maize cultivation), only a few scattered agricultural villages existed in this area. As per their study, during the above period of about 600 years, the soil erosion in the catchment led to the deposition of 2.3 million tons of sediments in the Pátzcuaro Lake. While in the subsequent period between 2500 and 1200 years BP, about 13.4 million tons of sediment got deposited in the lake. This increase in soil erosion was because the villages competed for land-based natural resources and thereby exerted more pressure on land. During 1200–1960 AD, the total sediment deposition in the lake has increased to an estimated quantity of 24.6 million tons. As per Farshad and Barrera-Bassols (2003), the rate of soil erosion in the catchment has drastically increased since the 1960s and more than 40% of the catchment area is under soil erosion. Accordingly, the sediment deposition in the lake has tremendously increased to the estimated quantity of about 64–140 Mm^3 per year, during 1960–1990 (Farshad and Barrera-Bassols 2003).

In North China, very severe water erosion had been found to occur in the deep and once fertile loessal soil in the Province of Shansi. Erosion was so severe that it had caused the formation of gullies which were as deep as 600 feet (Lowdermilk 1953). The silt load generated from the soil erosion was so heavy that it had put an irrigation system out of use, which was established in 746 BC.

In Spain, large-scale land use changes occurred during the 16th and 17th centuries as a consequence of the Christian rule and colonization in America (Puigdefábregas and Mendizabal 1998). The land use change took place mainly to meet the increased demands for wool and wood products of the American settlers (Puigdefábregas and Mendizabal 1998, Baartman et al. 2007). This resulted in the southward expansion of dryland agriculture, which was confined to the inner Iberian high plains. The land use changes have resulted in increased soil erosion (Puigdefábregas and Mendizabal 1998, Baartman et al. 2007).

The Great Plains region, a large expanse of flat land lying between the west of Mississippi River and east of the Rocky Mountains in the United States and Canada, suffered a decade of drought and crop failure during the 1930s. This region had mostly favourable climatic conditions in the 1920s with good rains that had encouraged increased settlement and cultivation in the Great Plains. However, during the decade starting with 1930, the Great Plains region faced several severe drought years which resulted in dry and arid conditions. The unsustainable agricultural management practices including deep ploughing were followed in the region. This worsened the impact of drought, damaging the crops that kept the soil in place. In addition, excessive cattle ranching and associated overgrazing had left many parts of the area devoid of natural grasses and shrubs that hold the soil and trapped moisture and, thereby, made the soil dehydrated and lacking in soil organic matter. Such situations made the soil more vulnerable to wind erosion. Because of the severe dry conditions, resulting due to the repeated severe droughts, the Great Plains suffered erosion and lost the top and the most productive soil. The continued dry conditions led to the failure of crops, leaving the ploughed agricultural fields more vulnerable to wind erosion. The problem got further worsened as the farmers did not take appropriate soil conservation measures. By the year 1936, this human-induced soil erosion had affected more than 25 Mha of land (Middleton and Thomas 1997). The persistent drought and the topsoil loss had led to the abandonment of farmsteads and ranches as well as caused financial losses to the local community, which resulted in widespread poverty and hunger. More than 500,000 people were left homeless. This situation had resulted in very large-scale migration from Great Plains to the neighbouring regions. Between 1930 and 1940, around 3.5 million people migrated from the Great Plains to find new sources of livelihood. This was the largest migration of people ever taken place in America's history.

Severe dry conditions and, as the surface was devoid of the indigenous grasses, the high winds created massive dust storms. During the next few years, the persistent dry conditions and the high wind led to several strong dust storm events in the region. These dust storms were so intense that the Great Plains' topsoil was taken away to very long distances and were deposited even in Washington DC, New York City and on ships 2,000 km away at sea in the Atlantic (Middleton and Thomas 1997). A reporter covering the Oklahoma dust storm of 14 April 1935 coined the term 'Dust Bowl' to describe the region and the massive dust storms. This is how the US Great Plains got the name 'Dust Bowl'. The 'Dust Bowl' of the US Great Plains is another example of the devastating human tragedy that can be caused by land degradation/desertification. During the 1950s, the drought and soil erosion returned to the Great Plains, once again, affecting even much larger areas (Middleton and Thomas 1997).

Though drought, aridity and land degradation of the 1930s in the Great Plains and their associated socio-economic implications had made the US government seriously think and take the appropriate measures towards mitigation of the impact of land degradation, this was not the first instance when land degradation became a serious problem in this area. It was reported to have occurred much earlier than the 'Dust Bowl' event. About 70 years prior to the 'Dust Bowl' event, during the 1860s, large-scale cattle ranching started in the plains as the railways were constructed by that time and the transportation of cattle to markets in the eastern United States became possible (Middleton and Thomas 1997). These large-scale ranching operations were mostly established through investments from Europe. High livestock density in some of the areas led to the problems of trampling, soil compaction as well as overgrazing, which resulted in the removal of short wiry grass species that gave protection from wind erosion. Such conditions have resulted in increased soil erosion in the region, even at that time. Another important thing that happened during this period was the federal government encouraged people to settle in the Great Plains for farming through the Homestead Act 1862, which offered 65 ha plots to settlers. As a result, the population in the area increased and the farming activities also increased tremendously. Inappropriate land use and land conversion had resulted in increased soil erosion.

In Australia, overgrazing of rangelands had been the main cause of land degradation. Rangelands occupy about 70% area of this continent with approximately 60% of that used for commercial pastoralism (Pickup 1998). During the time prior to the arrival of Europeans in Australia, the rangelands were used by hunter-gatherers and grazed by the native animals, mainly. After the arrival of Europeans in the middle of the 19th century, sheep and cattle were introduced from 1850 onwards (Pickup 1998). They grazed mostly around the natural water bodies, which were limited in numbers. Cattle ranching used to be confined to the places near the natural source of water and grazing activities were confined to areas around the water bodies only. However, by the early 20th century, due to overgrazing, severe land degradation took place around many of the water bodies. Massive losses of livestock took place during the drought years. In New South Wales, the number of sheep reduced from 19 million in the 1890s to 3.5 million in the drought of 1901–1902, which never recovered subsequently, probably because of land degradation (Pickup 1998). Soil erosion, salinization and waterlogging are the other processes of land degradation affecting large areas in Australia. The problem of salinization and waterlogging in irrigated land, saline seepage in drylands, increased during the first quarter of the 20th century as the cultivation got extended to the dryland areas (Dregne 1986).

The subsequent chapters will provide a detailed account of the DLD processes, causes and impact, the scientific methods of mapping, monitoring and quantifying the extent of land degradation, risk and vulnerability assessment, combating and mitigating strategies, as well as a brief account of the international efforts and programmes to tackle this global issue of environmental and social concern.

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